RESEARCH ARTICLE • OPEN ACCESS

The Effect of PBL Integrated Education for Sustainable Development on Students' Mathematical Communication and Problem Solving Skills

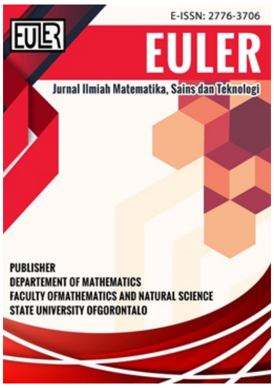
Puput Puput, Ahmad Yani T, Nurfadilah Siregar, and Verminus Verminus

Volume 14, Issue 1, Pages 238–247, April 2026

Received 10 January 2026, Revised 19 April 2026, Accepted 21 April 2026, Published 26 April 2026

To Cite this Article : P. Puput, A. Yani T, N. Siregar, V. Verminus,"The Effect of PBL Integrated Education for Sustainable Development on Students' Mathematical Communication and Problem Solving Skills", *Euler J. Ilm. Mat. Sains dan Teknol.*, vol. 14, no. 1, pp. 238–247, 2026, *https://doi.org/10.37905/euler.v14i1.37346*

JOURNAL INFO • EULER : JURNAL ILMIAH MATEMATIKA, SAINS DAN TEKNOLOGI



Homepage	:	http://ejurnal.ung.ac.id/index.php/euler/index
Journal Abbreviation	:	Euler J. Ilm. Mat. Sains dan Teknol.
Frequency	:	Three times a year
Publication Language	:	English (preferable), Indonesia
DOI	:	https://doi.org/10.37905/euler
Online ISSN	:	2776-3706
License	:	Creative Commons Attribution-NonCommercial 4.0 International License
Publisher	:	Department of Mathematics, Universitas Negeri Gorontalo
Country	:	Indonesia
OAI Address	:	http://ejurnal.ung.ac.id/index.php/euler/oai
Google Scholar ID	:	QF_r-_gAAAAJ
Email	:	euler@ung.ac.id

Euler : Jurnal Ilmiah Matematika, Sains dan Teknologi, Volume 14, Issue 1, Pages 238–247, April 2026 *https://doi.org/10.37905/euler.v14i1.37346*

Research Article

Check for updates

The Effect of PBL Integrated Education for Sustainable Development on Students' Mathematical Communication and Problem Solving Skills

Puput[1,*], **Ahmad Yani T**[1], **Nurfadilah Siregar**[1], **Verminus**[1]

[1] *Departemen of Mathematics Education, Universitas Tanjungpura, Pontianak 78124, Indonesia*

ARTICLE HISTORY
Received 10 January 2026
Revised 19 April 2026
Accepted 21 April 2026
Published 26 April 2026

KEYWORDS
Education for Sustainable Develoment
Mathematical Communication
Problem Solving Skills
Problem Based Learning

ABSTRACT. *This research adopted a pretest–posttest control group experimental design. The primary objective was to investigate the impact of implementing Problem-Based Learning (PBL) integrated with the Education for Sustainable Development (ESD) approach on students' mathematical problem-solving abilities and mathematical communication skills within the context of matrix learning. The population consisted of all 11th-grade students at SMAN 8 Pontianak ($N = 280$), with two classes selected through probability sampling as the experimental and control groups. Data were collected using essay tests, observations, and documentation, then analyzed using independent samples t-tests, Mann–Whitney tests, and effect size analyses. The findings indicated statistically significant differences between the experimental and control groups ($p < 0.05$). Specifically, the experimental group achieved a mean post-test score 20.21% higher than the control group in problem-solving and 36.41% higher in mathematical communication. Strong effect sizes ($d = 1.84$ and $r = 1.34$) further demonstrate that ESD-oriented PBL substantially improved students' competencies compared to conventional methods.*

1. Introduction

The landscape of 21st-century education demands that students possess robust mathematical proficiencies, particularly in problem-solving and communication [1, 2]. According to the NCTM, these two skills are fundamental standards that enable students to navigate global complexities and make analytical decisions [3, 4]. Despite their importance, recent PISA 2022 results indicate a decline in Indonesian students' average mathematics scores to 366, highlighting a significant weakness in higher-order thinking and the ability to resolve contextual problems [5].

This national trend is mirrored in specific topics like matrices. While matrices are foundational for multidisciplinary fields such as physics, economics, and computer science, student outcomes remain consistently low [6, 7]. Previous research identifies that students frequently struggle with non-routine matrix problems due to procedural errors and a lack of information management skill [8, 9]. Preliminary observations at SMAN 8 Pontianak confirmed this, where the average student score for matrices was only 63 below the minimum mastery criteria. Specifically, students' achievement in problem-solving and communication reached only 36% and 39% respectively, largely due to conventional, lecture-based instruction that lacks real-world application.

To address these gaps, *Problem-Based Learning* (PBL) offers a strategic solution by engaging learners with authentic, real-world issues to foster critical thinking and collaboration [10]. However, to make PBL more meaningful in the modern era, it must be contextualized with

*Corresponding Author.

Email : *f2181251011@student.untan.ac.id* (P. Puput)
Homepage : http://ejurnal.ung.ac.id/index.php/euler/index / E-ISSN : 2776-3706

global imperatives such as *Education for Sustainable Development* (ESD). The theoretical link between PBL and ESD lies in transformative pedagogy: while PBL provides the structural framework for inquiry-based learning, ESD provides the substantive context by introducing environmental, social, and economic sustainability issues as the "problems" to be solved [11, 12]. This integration empowers students to not only master abstract mathematical operations such as translating matrix word problems into representations but also to evaluate their solutions through the lens of global responsibility [13].

Previous studies indicate that the integration of social and environmental contexts in *Problem-Based Learning* (PBL), such as the concept of *Sedekah* or the principles of *Environmental, Social, and Governance* (ESG), significantly enhances students' communication skills [14, 15]. Furthermore, recent meta-analyses confirm that integrating PBL with multidisciplinary approaches such as ethnomathematics which shares conceptual roots with ESD has a profound impact on mathematical literacy, yielding a substantial effect size ($r = 1.42$) [16]. This indicates that the use of globally responsible modern contexts, such as energy management, can bridge the gap between standard curricula and the demands of 21st-century competencies.

Despite the proven individual merits of PBL and ESD, there is a scarcity of empirical evidence regarding their integrated impact on specific mathematical competencies. Most existing literature treats PBL as a cognitive tool and ESD as an affective awareness framework in isolation. This study addresses this gap by examining how an ESD-oriented PBL model can simultaneously improve mathematical problem-solving and communication skills within the context of matrix learning.

The research questions guiding this study are formulated as follows: 1) Is there a statistically significant difference in students' mathematical problem-solving abilities between the experimental group and the control group?; 2) Is there a statistically significant difference in students' mathematical communication abilities between the experimental group and the control group?; 3) To what extent is the PBL model oriented toward *Education for Sustainable Development* (ESD) effective in enhancing students' mathematical problem-solving abilities in matrix learning?; and 4) To what extent is the PBL model oriented toward *Education for Sustainable Development* (ESD) effective in improving students' mathematical communication abilities in the matrix topic?

2. Methods

2.1. Research Design and Participants

This research employed a quasi-experimental approach with a *Pretest-Posttest Control Group Design*. The population comprised 280 eleventh-grade students at SMAN 8 Pontianak, distributed across eight classes. A probability sampling technique, specifically cluster random sampling, was utilized to select two classes as the study sample. Class XI E was assigned as the experimental group, while Class XI D served as the control group; this assignment was justified by a homogeneity test of the students' prior academic records to ensure an equivalent baseline. To guarantee the study's internal validity and teacher consistency, both groups were instructed by the same mathematics teacher over a period of four intensive sessions (3×45 minutes per meeting). The experimental group received the *Problem-Based Learning* (PBL) model integrated with *Education for Sustainable Development* (ESD), where students engaged with matrix-related sustainability issues, such as managing electrical energy consumption. In contrast, the control group was taught using the STAD model based on the Scientific Approach, focusing on heterogeneous teamwork and individual quizzes.

2.2. Intervention and Implementation Control

The experimental group received instruction using a *Problem-Based Learning* (PBL) model oriented toward *Education for Sustainable Development* (ESD), while the control group was taught using the *Student Teams Achievement Division* (STAD) model. To ensure sufficient exposure and address concerns regarding treatment duration, the intervention was conducted over four instructional sessions (two meetings per week), with each session lasting 3×45 minutes. The duration was designed to adequately cover matrix material and allow observable development of students' cognitive abilities. To maintain internal validity, both groups were taught by the same mathematics teacher with more than ten years of teaching experience. This control minimizes teacher-related variability.

The five sequential phases (syntax) used in the implementation of the PBL model oriented towards ESD on the topic of matrices are shown in Table 1.

Table 1. The implementation of the PBL model oriented ESD

Syntax	Activity
Orient the Students to the Problem	The teacher presents a contextual problem linked to matrices and a sustainability issue (e.g., using matrix data to manage electrical energy consumption in the school). Students are guided to comprehend the problem and the learning objectives.
Organize Students for Study	Students are divided into small groups. The teacher clarifies the group task, the work procedure, and the expected product or solution.
Guide Individual and Group Investigation	Students identify the necessary information and the relevant matrix concepts required. Groups engage in discussion to collect data and formulate solution ideas. The teacher acts as a facilitator by posing provocative or triggering questions.
Develop and Present the Solution	Groups construct the solution using matrix operations. Each group presents their findings to the class. Other groups provide feedback or responses.
Reflect and Evaluate	The teacher and students collaboratively reflect on the learning process, the material content, and the connection between matrices and ESD values. Emphasis is placed on understanding the concepts and the benefits of their real-world application.

The five phases (syntax) used in applying the STAD-Scientific Approach model to the topic of matrices are shown in Table 2.

Table 2. The STAD oriented scientific approach model

Syntax	Activity
Present the Material (Observing & Questioning)	The teacher presents the fundamental matrix concepts (definition, order, types) through contextual examples. Students observe the presentation and pose questions related to the real-life application of matrices.
Team Work (Data Collecting & Reasoning)	Students are grouped into heterogeneous, peer-based teams. They discuss solving matrix operation problems (addition, subtraction, multiplication) and collaboratively assist each other in understanding the solution steps.
Individual Quiz (Associating/Analyzing)	Each student independently completes an individual quiz on matrix operations without team assistance to measure their respective understanding.
Individual Improvement Score (Assessing)	The teacher calculates each student's score improvement compared to their previous score to assess individual learning progress.
Team Recognition (Communicating)	The teacher announces the best teams based on the average improvement score and provides awards. Group representatives present their discussion results or matrix problem-solving strategies.

2.3. Intervention and Implementation Control

To measure the dependent variables, this study employed a set of three non-routine essay problems on matrix topics. The use of multiple items was intended to ensure content validity and adequately represent the constructs of problem solving and mathematical communication. Each item was designed as a contextual and open-ended problem, integrating real-world situations aligned with sustainability issues (ESD context), requiring students to construct mathematical models, apply matrix operations, and interpret results.

The research data were gathered through a test of mathematical problem solving and communication ability. The instrument used was a single essay question designed to incorporate indicators for both competencies. The problem-solving indicators assessed followed the four stages defined: 1) Understanding the problem; 2) Devising a plan; 3) Carrying out the plan; and 4) Looking back (Checking the solution) [19]. Concurrently, the test also integrated the following mathematical communication indicators: 1) The ability to relate real-world objects, visual representations, and diagrams to mathematical concepts; 2) The ability to explain mathematical concepts, situations, and relationships through written communication; and 3) The ability to express events or ideas using appropriate mathematical language and symbols [15, 16].

Initially, three non-routine word problems on the matrix topic covering data representation, matrix operations, and matrix transpose were piloted. From these, one item was selected based on its moderate difficulty level, validity, and reliability. A single essay question was deemed sufficient to simultaneously measure both problem-solving and mathematical communication skills. This is because the problem-solving process involves stages of understanding the problem, planning a solution, executing the plan, and evaluating the results, all of which inherently require clear written explanation [19]. Mathematical communication is demonstrated when students clearly articulate their ideas, strategies, and reasoning in a sequential manner [9]. Consequently, a contextual essay question assesses not merely the final answer, but critically evaluates the student's thought process and the effectiveness of their mathematical conveyance.

The use of non-routine and open-ended problems is supported by Guilford's theory of divergent thinking, which states that complex tasks can capture multiple cognitive dimensions through a single rich stimulus [22]. In this study, each item was constructed as a *rich-task* problem, requiring a chain of reasoning that integrates both problem-solving processes and communication skills. Thus, although the number of items is limited, each task contains multi-step sub-processes, ensuring that students' abilities are assessed comprehensively rather than through fragmented questions.

2.4. Data Analysis

The research instrument's validity and reliability were established through a rigorous pilot study involving three non-routine essay problems covering matrix representation, operations, and transpose. While all three items were found to be statistically valid, only one item was selected for the final instrument based on its difficulty index. Following Arikunto's criteria, a high-quality test item should neither be too easy nor too difficult; items that are too simple fail to stimulate students' problem-solving efforts, while overly complex items may discourage engagement [23]. The selected item possessed a moderate difficulty level, making it the most effective tool for discriminating between students' actual abilities.

Although the final instrument consisted of a single item, its use is theoretically supported by Guilford's divergent thinking framework. A single, complex, open-ended "rich task" can effectively capture multifaceted cognitive dimensions specifically mathematical problem-solving and communication by requiring students to elaborate on diverse logical paths and strategies [22]. To ensure objective evaluation, student responses were scored using a structured analytic rubric (scale 0–4 per indicator), and inter-rater reliability was confirmed between the researcher and a senior mathematics teacher, yielding a Cohen's Kappa of $\kappa = 0.82$ (strong agreement).

Statistical analyses were performed using *IBM SPSS 25*. Prior to hypothesis testing, normality was assessed using the Shapiro–Wilk test. The results indicated that problem-solving data followed a normal distribution ($p > 0.05$), whereas mathematical communication data violated the normality assumption ($p < 0.05$). Consequently, the *Independent Samples t-test* was used for problem-solving analysis, while the *Mann–Whitney U test* was employed for mathematical communication. To address the reviewer's request for practical significance, the effect size was calculated using Cohen's d for parametric data and the r value ($r = Z/N$) for non-parametric data. This comprehensive approach ensures that the findings are robust and the magnitude of the ESD-oriented PBL model's impact is clearly quantified.

3. Results and Discussion

3.1. *Pre-test*

The pre-test analysis was conducted to examine the initial equivalence between the experimental and control groups. For mathematical problem-solving ability, the *Independent Samples t-test* indicated no statistically significant difference between the two groups ($t = 0.461$; $p = 0.646 > 0.05$), as presented in Table 3.

Table 3. Descriptive analysis of problem solving pre-test scores in the control and experimental classes

Class	N	Mean	SD	sig
Control	32	58.09	11.02	0.646
Experimental	32	56.72	12.75	

Similarly, the Mann–Whitney U test results for mathematical communication showed no significant difference ($z = 0.193$; $p = 0.847 > 0.05$), as shown in Table 4.

Table 4. Descriptive analysis of mathematical communication pre-test in the control and experimental classes

Class	N	Mean	SD	sig
Control	32	42.47	15.06	0.847
Experimental	32	43.34	15.17	

These results indicate that both groups had comparable initial abilities prior to the intervention, confirming that the groups were statistically equivalent. This baseline similarity strengthens the internal validity of the study and ensures that post-test differences can be attributed to the treatment.

3.2. *Post-test*

The post-test results revealed statistically significant differences between the experimental and control groups. For mathematical problem-solving ability, the *Independent Samples t-test* showed a significant difference ($t = 3.674$; $p = 0.001 < 0.05$), with the experimental group outperforming the control group, as presented in Table 5.

Table 5. Descriptive analysis results of problem solving post-test scores for control and experimental classes

Class	N	Mean	SD	sig
Control	32	61.19	12.39	0.001
Experimental	32	73.56	14.46	
Extent of effectiveness of the model, $ES = 1.84$ (in high category)				

The results demonstrate that the implementation of the PBL model oriented toward *Education for Sustainable Development* (ESD) successfully enhanced students' mathematical problem solving ability on the matrices topic, yielding an Effect Size ($ES = 1.84$), which falls within the high category of effectiveness.

The statistical superiority of the experimental group indicates that the PBL-ESD framework provided a more robust scaffolding for students to navigate the complexity of non-routine matrix problems. Specifically, while the control group struggled to move beyond procedural calculations, students in the experimental group demonstrated a more sophisticated ability to translate sustainability data such as energy consumption or waste management into systematic matrix representations.

The very large effect size ($ES = 1.84$) in problem-solving is justified by the transformative nature of the ESD context. Unlike routine drills, the sustainability issues presented acted as "rich tasks" that increased students' cognitive engagement and intrinsic motivation. This high level of engagement allowed students to persist longer in the "looking back" stage of Polya's framework, ensuring their solutions were not only mathematically correct but also contextually logical.

The post-test mean scores differed significantly between the experimental and control groups in mathematical communication ability on the matrices topic ($z = 5.632$; *sig* $= 0.001$; $p < 0.05$). Due to the statistically significant disparity observed between the two groups, the Effect Size (ES) calculation was subsequently performed to evaluate the model's effectiveness, as presented in Table 6.

Table 6. Descriptive analysis results of mathematical communication post-test scores for control and experimental classes

Class	N	Mean	SD	sig
Control	32	49.16	12.61	0.001
Experimental	32	67.06	14.47	
Extent of effectiveness of the model, $ES = 1.34$ (in high category)				

The results demonstrate that the implementation of the PBL model oriented toward ESD successfully enhanced students' mathematical communication ability on the matrices topic, yielding an Effect Size ($ES = 1.34$), which falls within the high category of effectiveness.

Deeper interpretation of this result suggests that the social-constructivist nature of PBL-ESD encouraged more intensive mathematical discourse. Students were required to articulate, argue, and clarify their matrix-based models in the context of global challenges. This constant need for verbal and symbolic clarification during group investigations significantly accelerated their communication proficiency compared to the more teacher-centered STAD approach in the control group.

The pre-test results indicate that students in both the experimental and control groups possessed comparable levels of mathematical problem-solving and communication skills prior to the intervention. This baseline equivalence resonates with the challenges highlighted in the introduction, where Indonesian students generally demonstrate a weak mastery of higher-order thinking skills [3, 5]. Such low initial proficiency reflects a widespread difficulty in articulating, understanding, and presenting mathematical ideas, particularly when faced with non-routine contextual problems [9]. Furthermore, as previously discussed, students with low initial ability often struggle with modeling abstract mathematical concepts, such as matrices, because they lack the linguistic and information-management skills necessary to dissect complex problems [4].

After the implementation of the PBL model oriented toward ESD, different outcomes were observed between the two groups. For instance, a study involving students from regular and Islamic schools in Indonesia demonstrated an evident increase in mathematical communication abilities emerged when project-based learning was applied using the concept of *Sedekah* as its contextual foundation [17].

Furthermore, the integration of PBL with ethnomathematics a concept closely related to the cultural and social pillars of ESD has been empirically validated. A recent meta-analysis involving 20 effect sizes concluded that such integrated models have a very strong impact on mathematical literacy, yielding an effect size of $r_{RE} = 1.42$ ($Z = 9.817$; $p < 0.001$) [16]. This supports the high effect size found in the current study, suggesting that when PBL is combined with multidisciplinary contexts, the impact on student proficiency is consistently substantial.

The parity observed in the pre-test results confirms that students in both groups faced similar initial hurdles. This condition mirrors the findings of [22, 23], where a qualitative analysis of 11th-grade students' work on matrix problems revealed that many students remain in the "low" category of problem-solving. This is largely because they fail to consistently execute all four stages of Polya's framework specifically in the planning and re-checking phases [22]. The implementation of the ESD-oriented PBL model in this study was designed precisely to overcome these systemic gaps by providing a structured inquiry process.

The effectiveness of this approach is further supported by the integration of contextual elements, such as ethnomathematics, which shares conceptual roots with ESD in emphasizing real-life relevance. As demonstrated by [26], the synergy between *Problem-Based Learning* and ethnomathematics significantly outperforms conventional learning models in enhancing mathematical understanding. While [25, 26] noted a unique challenge where students sometimes prefer modern contexts over local culture, the use of ESD in this study (e.g., energy management) provided a "modern" yet globally responsible context that successfully bridged this gap, resulting in a high effect size ($d = 1.84$).

It was also found that the implementation of the PBL model oriented toward ESD successfully improved students' mathematical communication ability. For instance, [18] demonstrated that the implementation of PBL integrated with *Environmental, Social, and Governance* (ESG) principles effectively enhances students' learning motivation, innovation skills, and communication abilities. This outcome supports the notion that sustainability-oriented PBL is a suitable approach for reinforcing sustainability literacy and 21st-century competencies in higher education. Consistent with this, [16] in their study showed that the application of PBL integrated with ethnomathematics had a significantly powerful influence on children's mathematical literacy ($r_{RE} = 1.42$; $Z = 9.817$; $p < 0.001$). Education should not only focus on the mastery of technical knowledge but also on comprehensive personal development through critical thinking, self-directed learning, and social responsibility [28]. Aligning with this view, ESD-oriented mathematics instruction encourages students to connect mathematical concepts with real social and ecological contexts, thereby developing communication, collaboration, and critical reflection skills concerning sustainability issues [29]. In mathematics learning, PBL provides a natural space for students to discuss ideas, articulate mathematical reasoning, and interpret the perspectives of their group members, which organically fosters the development of mathematical communication ability [30, 31]. This is consistent with Vygotsky's social constructivism perspective that social interaction is key to building knowledge and thinking skills, including the ability to communicate mathematical ideas [32].

4. Conclusion

The results of this study suggest that the integration of *Education for Sustainable Development* (ESD) within a *Problem-Based Learning* (PBL) framework provides a promising pedagogical approach for teaching matrix algebra. Statistical analyses indicate significant differences in students' mathematical problem-solving and communication performance in favor of the experimental group compared to the STAD-Scientific approach. These findings imply that contextualizing abstract matrix operations through sustainability-driven "rich tasks" can effectively stimulate higher-order thinking and mathematical discourse.

However, these conclusions are specific to the context of this study and should not be overgeneralized. The observed effectiveness is bounded by several methodological limitations, including the intensive but brief intervention period and the use of a single, albeit comprehensive, non-routine essay instrument. Factors such as the novelty of the ESD context and variations in students' prior mathematical foundations may also have influenced the magnitude of the effect sizes.

Consequently, future research should investigate the long-term retention of these skills and test the model across more diverse mathematical topics and larger sample sizes. For practitioners, the findings support the gradual adoption of ESD-oriented PBL in secondary mathematics, provided that teachers are equipped with structured instructional designs that bridge the gap between curriculum standards and sustainability issues.

Author Contributions. **Puput Puput**: Conceptualization, writing original draft, editing, and visualization. **Ahmad Yani T**: Methodology, formal analysis, validation, and writing review & editing. **Nurfadilah Siregar**: validation, supervision, and writing review & editing. **Verminus Verminus**: Data collection, investigation, and data curation.

Acknowledgment. The author gratefully acknowledges SMAN 8 Pontianak for the permission to conduct this study. Special thanks are also addressed to the mathematics teachers who participated in this research and contributed support throughout the data collection phase.

Funding. This study received no external funding.

Conflict of interest. The authors report no conflicts of interest associated with this article.

Data availability. Not applicable.

References

[1] S. Gretter and A. Yadav, "Computational Thinking and Media & Information Literacy: An Integrated Approach to Teaching Twenty-First Century Skills," *TechTrends*, vol. 60, no. 1, pp. 510–516, 2016, doi: 10.1007/s11528-016-0098-4.

[2] A. E. Febriana and H. Pujiastuti, "Analisis 21st Century-Learning Design: Kemampuan Komunikasi Matematis Mahasiswa Pendidikan Matematika Pada Mata Kuliah Teori Peluang," *J. Pembelajaran Mat. Inov.*, vol. 5, no. 3, pp. 649–658, 2022, doi: 10.22460/jpmi.v5i3.649-658.

[3] H. Hendriana and U. Soemarmo, *Penilaian pembelajaran matematika*. Refika Aditama, 2014.
[4] Microsoft, *Transform learning with 21st century learning design*. Microsoft, 2021.
[5] B. Kurniawan and N. P. K. Widiastuti, *Media Pembelajaran Multimedia Interaktif Epic 5C Berbasis CBL*. Penerbit Widina, 2022.
[6] R. Ariawan and H. Nufus, "Hubungan Kemampuan Pemecahan Masalah Matematis dengan Kemampuan Komunikasi Matematis Siswa," *THEOREMS*, vol. 1, pp. 82–91, 2017.
[7] H. T. Laia and D. Harefa, "Hubungan Kemampuan Pemecahan Masalah Matematis dengan Kemampuan Komunikasi Matematik Siswa," *Aksara J. Ilmu Pendidik. Nonform.*, vol. 7, no. 2, p. 463, 2021, doi: 10.37905/aksara.7.2.463-474.2021.
[8] Z. Šimunović and V. Vekić-Kljaić, "Competencies for the 21st Century: Is Education Keeping up with Industry 4.0?," *Lect. Notes Networks Syst.*, vol. 1070, pp. 335–343, 2024, doi: 10.1007/978-3-031-66271-3_36.
[9] National Council of Teachers of Mathematics, *Principles and Standards for School Mathematics*. NCTM, 2000.
[10] H. Palayukan *et al.*, "Analisis Pemecahan Masalah Matematika Dan Komunikasi Matematik Mahasiswa Dengan Penerapan Model Project-Based Learning (PjBL) Terintegrasi Etnomatematika," vol. 5, pp. 1–15, 2024.
[11] D. C. Simamora *et al.*, "Pengaruh strategi PBL dan TPS terhadap kemampuan pemecahan masalah dan kemampuan komunikasi matematis," *Primatika J. Pendidik. Mat.*, vol. 12, no. 1, pp. 9–18, 2023, doi: 10.30872/primatika.v12i1.1474.
[12] H. Palayukan *et al.*, "Analisis Pemecahan Masalah Matematika Dan Komunikasi Matematik Mahasiswa Dengan Penerapan Model Project-Based Learning (PjBL) Terintegrasi Etnomatematika," vol. 5, pp. 1–15, 2024.
[13] E. Susanti and Hartono, "An analysis mathematical problem solving and mathematical critical thinking skills of junior high school students," *J. Phys. Conf. Ser.*, vol. 1320, no. 1, 2019, doi: 10.1088/1742-6596/1320/1/012071.
[14] Anwar, D. Juandi, and S. Y. Ningsih, "Education for sustainable development: investigating the sustainability consciousness and mathematical competence," *J. Phys. Conf. Ser.*, vol. 1521, no. 3, 2020, doi: 10.1088/1742-6596/1521/3/032068.
[15] A. Stokes and N. Harmer, "The value of 'having a go': Trialing a project-based learning activity to inform curriculum design," *J. Geosci. Educ.*, vol. 66, no. 4, pp. 278–292, 2018.
[16] F. I. Sholihah, "A Meta-Analysis of Problem-Based Learning Integrated with Ethnomathematics to Improve Children's Mathematical Literacy," *J. Obsesi*, vol. 9, no. 2, pp. 573–582, 2025, doi: 10.31004/obsesi.v9i2.6887.
[17] Nurniqta *et al.*, "Improvement in mathematical communication skills through PBL contextualized in Sedekah," *Math. Educ. J.*, vol. 19, no. 3, pp. 609–628, 2025, doi: 10.22342/mej.v19i3.pp609-628.
[18] C. T. Chien, "Evaluating Problem-Based Learning in an ESG-Centered General Education Course," *Sustainability*, 2025.
[19] G. Pólya, *How to solve it: A new aspect of mathematical method*. 2014.
[20] N. Nari, "Kemampuan Komunikasi Dan Disposisi Matematis Mahasiswa Pada Mata Kuliah Geometri," *Ta'dib*, vol. 18, no. 2, p. 150, 2015, doi: 10.31958/jt.v18i2.287.
[21] L. L. A. Suhenda and D. R. Munandar, "Kemampuan Komunikasi Matematis Siswa Dalam Pembelajaran Matematika," *J. Educ. FKIP UNMA*, vol. 9, no. 2, pp. 1100–1107, 2023, doi: 10.31949/educatio.v9i2.5049.
[22] J. P. Guilford, *The Nature of Human Intelligence*. New York: McGraw-Hill, 1967.
[23] A. S, *Dasar-Dasar Evaluasi Pendidikan*. Jakarta: Bumi Aksara, 2005.
[24] S. Rahayu *et al.*, "Analysis of high school students' mathematical problem-solving abilities on matrix content," *PowerMathEdu*, vol. 3, no. 2, pp. 209–224, 2024.
[25] E. Njurai and A. Uworwabayeho, *Impacts of globalization and innovation in mathematics education*. 2024, doi: 10.4018/979-8-3693-2873-6.
[26] R. A. Pratama and R. Afriani, "The effect of ethnomathematics-based learning on students' mathematical problem-solving skills," *SN Soc. Sci.*, vol. 5, no. 11, p. 204, 2024, doi: 10.20944/preprints202403.1551.v1.
[27] D. C. Perdana and I. Isrokatun, "Problem-based learning and ethnomathematics on mathematical understanding," *J. Phys. Conf. Ser.*, vol. 1318, no. 1, 2019, doi: 10.1088/1742-6596/1318/1/012134.
[28] G. M. Chans *et al.*, "Exploring transversal competencies in engineering students through international experiences."
[29] S. A. Tesfamicael and O. Enge, "Revitalizing Sustainability in Mathematics Education," *Educ. Sci.*, vol.

14, no. 2, p. 174, 2024.

[30] U. D'Ambrosio, *Ethnomathematics: Link between Traditions and Modernity*. 2006, doi: 10.1016/j.sbspro.2010.12.052.

[31] Hidayati *et al.*, "Improving students' mathematical communication skills through problem based learning," *J. Phys. Conf. Ser.*, vol. 1460, no. 1, 2020, doi: 10.1088/1742-6596/1460/1/012047.

[32] J. Ehrhardt, "Online Social Constructivism: Theory vs. Practice," in *Digital Literacy: Concepts, Methodologies, Tools, and Applications*, 2012, pp. 1335–1349.