



STEM-ESD Project on Plastic Waste to Improve Students' Integrative Knowledge and Sustainability Action

Layla Oktavia Widodo¹, Ari Widodo¹, Eliyawati¹, Ikmanda Nugraha¹, Putra Habib Dhitareka^{1*}

¹International Program on Science Education, Faculty of Mathematics and Natural Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia

DOI: 10.62345 /jese.v6i2.6004

Article Info

Received 18 March 2026

Accepted 30 April 2026

Published 30 September 2026

Keywords:

**Integrative Knowledge,
Plastic Waste,
STEM-ESD,
Sustainability Action**

*Corresponding author:

Putra Habib Dhitareka

Universitas Pendidikan Indonesia

E-mail: putra.habib.d@upi.edu

Abstract

Plastic waste is a difficult environmental problem to address, and school cafeterias, which often use single-use plastics, contribute to this problem. However, many schools have not yet implemented sustainable practices, and students are often limited to theoretical learning that rarely links scientific concepts to real-world environmental issues. Therefore, this study aims to examine the improvement in junior high school students' integrative knowledge and sustainability actions through a STEM-ESD project on plastic waste. A non-equivalent pretest-posttest quasi-experimental design was used, involving 62 seventh-grade students from a junior high school in Cikarang, Indonesia. Data resulted that the experimental class achieved a moderate increase in integrative knowledge (N-Gain = 0.31), while the control class showed a low (N-Gain = 0.26). Both classes demonstrated low improvement in sustainability action (N-Gain of 0.11 and 0.10, respectively), with no significant difference between them. These findings suggest that while STEM-ESD projects effectively develop students' ability to integrate scientific concepts with environmental issues, they are insufficient for driving significant behavioral change within a short timeframe.

INTRODUCTION

Plastic waste has become one of the most pressing global environmental challenges. The world produces 415 million tons of plastic waste annually, with less than 10% being recycled (Maitlo et al., 2022). The remainder pollutes both land and ecosystems, causing ecological degradation and socio-economic consequences (Putra et al., 2024). This crisis threatens the achievement of multiple Sustainable Development Goals (SDGs): SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 11 (Sustainable Cities) (United Nations, 2015).

In Indonesia, plastic waste remains unresolved. National waste generation in 2023 reached approximately 56.63 million tons, with plastic waste ranking second after food waste (KLH-BPLH, 2025). Purwaningrum (2016) noted that waste accounts for 14% of Indonesia's total waste. In schools, canteen activities remain heavily dependent on disposable packaging (Heiges et al., 2022). Research by Dey et al. (2021) indicated that schools generated approximately 70% of plastic waste from disposable packaging, with canteen single-use plastic waste reaching up to 42.71% in some areas (Littaqwa et al., 2025). On a broader scale, plastic straw consumption in Indonesia is extremely high, reaching up to 93,244,847 straws per day, placing the country fourth globally in terms of plastic straw waste production (Darmawan et al., 2022; Hermawan et al., 2021). Despite this, many schools lack comprehensive waste management policies. Schools should serve as strategic spaces for fostering sustainability practices (Bauer & Morlock, 2025).

Education for Sustainable Development (ESD) empowers learners to critically examine the root causes of sustainability and equip them with the competencies to take informed action (UNESCO, 2017). To address these challenges, ESD can be integrated with STEM (Science, Technology, Engineering, and Mathematics) learning (Muliakoswara et al., 2024). STEM education integrates four disciplines within a problem-solving framework (Bybee, 2013; English, 2016). When integrated with ESD, STEM provides scientific solutions to address

sustainability issues (Campbell & Speldewinde, 2022). Through STEM-ESD, students analyze problems scientifically and design solutions, developing integrative knowledge (Cardoso et al., 2025).

Integrative knowledge refers to students' ability to synthesize concepts from various disciplines to solve complex problems (Weng et al., 2022). In the plastic waste project, students connect science (polymer properties), technology (processing tools), engineering (design principles), and mathematics (calculation). This holistic understanding forms the cognitive foundation for innovative solutions (Aziza et al., 2024; Ivasyk & Voytovych, 2025). Sustainability actions represent behavioral change and environmentally conscious decision-making (Hossain et al., 2025). According to the Theory of Planned Behavior (Ajzen, 1991), behavioral intentions are shaped by attitude, subjective norm, and perceived behavior control. Through direct, hands-on involvement in waste management, students develop positive attitudes and confidence (Indriani et al., 2025).

Previous studies integrating STEM-ESD focused on cognitive outcomes like critical thinking and sustainability awareness, not on sustainability actions (Annisa et al., 2024). Research on plastic waste projects often focused on knowledge and skills partially (Linarti et al., 2025; Nagatomo, 2024; Parejo et al., 2021). Research simultaneously investigating both integrative knowledge and sustainability action remains scarce, particularly at junior high school level. This study bridges this gap by implementing a STEM-ESD project on plastic waste to improve both competencies simultaneously. This research addresses (1) How is the improvement of students' integrative knowledge through a STEM-ESD project on plastic waste? (2) How is the improvement of students' sustainability action through a STEM-ESD project on plastic waste?

METHOD

This study employed a quantitative research approach using a quasi-experimental design with a non-equivalent control group pretest-posttest format (Capili & Anastasi,

2024). Two intact classes were assigned to either an experimental class ($n = 31$) or a control class ($n = 31$). The population in this study was seventh-grade junior high school students at one of the schools in Cikarang that implemented the *Merdeka Curriculum*. The sample comprised 62 students selected through convenience sampling. The study participants consisted of entire classes; therefore, random assignment was not possible. Both classes were taught by the same science teacher to minimize the teacher effect. The intervention took place over three sessions spanning approximately three weeks. Because the quasi-experimental design involved only one class per condition, class effects may be confounded with treatment effects; therefore, causal conclusions must be interpreted with caution.

Two instruments were used: (1) Integrative knowledge written test open-ended questions assessing: contextual saliency (3 items), knowledge connectedness (3 items), and deep conceptual understanding (3 items), with a total of 9 items. The scoring rubric adapted from Liu et al. (2022) and Ye et al. (2024) categorized performance into novice (0-33), intermediate (34-66), and expert-like (67-100). Content validity was established through expert evaluation conducted by science education lecturers. Construct validity was tested using Pearson's correlation coefficient, and one item (Q7) was deemed invalid and therefore removed. Reliability was calculated using Cronbach's alpha. (2) Sustainability action questionnaire modified from the Environmental Citizenship Questionnaire (ECQ) (Hadjichambis & Paraskeva-Hadjichambi, 2020), measuring past, present actions, future actions, and competencies, with a total of 20 items using a 4-point Likert scale. The modified instrument was revalidated through expert review and pilot testing. Several items were deemed invalid and were removed. The reliability coefficient for the action indicators was 0.688, while that for the competency indicators was 0.629, indicating acceptable internal consistency.

The experimental class engaged in a six stages STEM-ESD project (Widodo, 2021): problem formulation, planning, creating,

testing, redesigning, and communication. The project involved observing plastic waste in the school environment, designing solutions, creating products (eco-bricks, wall decorations from plastic straws, and plant pots from plastic cups), and socializing outcomes. The control class received discovery learning on environmental pollution, which included stimulation, problem statement, data collection, data processing, verification, and generalization. Both classes completed pre-test and post-test for integrative knowledge and sustainability action.

Data were analyzed using SPSS. Normality was tested with Shapiro-Wilk, homogeneity with Levene's test. Hypothesis testing used independent t-tests. Normalized gain was calculated in order to determine the extent of improvement from the pre-test to the post-test in each group using $g = (\text{Post-test score} - \text{Pre-test score}) / (\text{Maximum Score} - \text{Pre-test})$, categorized as high ($g > 0.7$), moderate ($0.3 < g \leq 0.7$), low ($g \leq 0.3$) (Coletta, 2023).

RESULT AND DISCUSSION

The data on integrative knowledge was measured through three indicators: contextual saliency, knowledge connectedness, and deep understanding conceptual. Data were collected through pre-test and post-test administered to both experimental and control classes before and after learning intervention.

Before conducting parametric statistical analysis, preliminary tests were performed to ensure the validity of the data. The Shapiro-Wilk normality test was used because each class had fewer than 50 participants, with a significance level of $\alpha = 0.05$. Levene's test was used to examine the homogeneity of variances between the two classes. The results are presented in Tables 1 and 2.

Table 1. Normality test results on integrative knowledge

Data	Normality test
Pre-test	0.160
Experiment	

Pre-test Control	0.132
Post-test Experiment	0.112
Post-test Control	0.226

As presented in Table 1, all data showed significance values greater than 0.05, indicating the data for both classes at both pre-test and post-test were normally distributed.

Table 2. Homogeneity test results on integrative knowledge

Data	Homogeneity test
Pre-test	0.519
Post-test	0.637

Based on Table 2, the significance values for both the pre-test and post-test were greater than 0.05, indicating that the two classes had homogeneous variances. These results confirm that the assumptions of normality and homogeneity are met, thus allowing the use of parametric tests.

After the significance test was conducted, an independent samples t-test was performed to determine whether there was a significant difference in integrative knowledge between the experimental and control classes. The analysis was conducted on the pre-test and post-test data, with the results presented in Table 3.

Table 3. Descriptive analysis test of integrative knowledge

Data type	Pre-test		Post-test	
Class	Experiment	Control	Experiment	Control
Mean	61.65	65.23	77.06	74.06
Standard Deviation	11.72	14.83	10.51	12.14
Independent t-test	0.296		0.355	

Based on Table 3, the pre-test analysis show no significant difference between the experimental class and the control class, with a p-value of 0.296. This indicates that both classes had equivalent prior knowledge before the learning intervention. After the intervention, the post-test results showed an increase in the mean scores for both classes. However, the t-test yielded a p-value of 0.355, indicating no statistically significant

difference between the two classes after the intervention.

This analysis measures the actual improvement achieved by students relative to the maximum possible improvement, thereby providing a more meaningful interpretation of learning gains (Coletta, 2023; Hake, 1998). The results are presented in Table 4.

Table 4. N-Gain analysis of integrative knowledge

Data	N-Gain	Category
Experiment	0.31	Moderate
Control	0.26	Low

Based on Table 4, the experimental class achieved an N-Gain of 0.31, which falls into the moderate improvement category, while the control class achieved 0.26, which is categorized as a low. This indicates that although the STEM-ESD project yielded a slightly higher improvement compared to conventional instruction, the difference was not statistically significant.

The distribution of students' score levels, as presented in Figure 1.

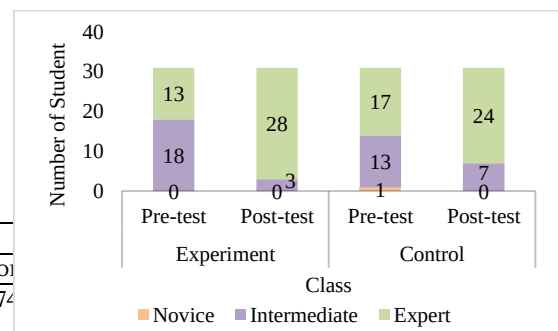


Figure 1. Students' score levels of integrative knowledge

Figure 1 illustrates the distribution of students' integrative knowledge scores following the learning intervention, categorized into three performance levels: beginner (scores 0–33), intermediate (34–66), and expert (67–100) based on a rubric adapted from Liu et al. (2022). In the experimental class, 28 students reached the expert level, 3 students reached the intermediate level, and none were at the beginner level. In the control class, 24 students reached the expert level, 7

students reached the intermediate level, and none were at the beginner level. This distribution indicates that both learning approaches successfully led students to a higher level of understanding, with the experimental class showing a slightly higher proportion of students at the expert level.

To examine these gains more specifically, Figure 2 presents students' scores across each integrative knowledge indicators.

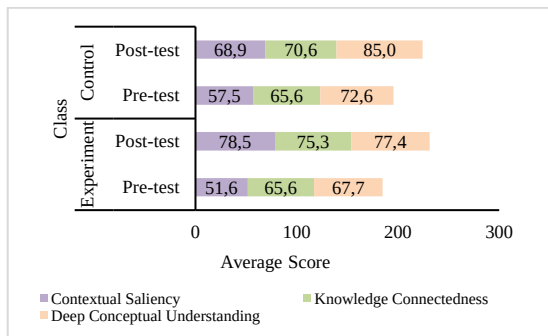


Figure 2. Students' scores per integrative knowledge indicator

Figure 2, shows that both learning approaches successfully took students from the beginner level to the intermediate level in terms of understanding, even though the STEM-ESD approach showed a slightly higher proportion of students reaching the expert level. To strengthen the study, the N-Gain for each of the integrative knowledge indicators listed in Table 5 was also calculated.

Table 5. N-Gain analysis of integrative knowledge indicators

Indicator	Class	N-Gain	Category
Contextual Saliency	Experiment	0.38	Moderate
	Control	0.25	Low
Knowledge Connectedness	Experiment	0.18	Low
	Control	0.15	Low
Deep Understanding	Experiment	-0.21	Decrease
	Control	0.41	Moderate

Based on Table 5, the analysis of students' integrative knowledge across these three indicators, distinct patterns of improvement emerged between the experimental and control classes. The most notable finding was observed in the contextual relevance

indicator, where the experimental class achieved a moderate N-Gain of 0.38, far surpassing the control class, which achieved only 0.25. This significant difference indicates that the STEM-ESD project is far more effective in helping students understand the relevance of their knowledge to real-world environmental issues. These findings align with research by Coutts et al. (2022), which found that sustainability concepts become contextually relevant when linked to students' everyday experiences and contexts. Through STEM learning, students are encouraged to develop multidisciplinary skills and use technology to solve complex real-world problems (Zadorozhna et al., 2024).

For the knowledge connectedness indicator, the experimental class achieved a low N-Gain value of 0.18, while the control class showed a negative N-Gain value of 0.15. Although both classes showed minimal improvement, the experimental class still performed better than the control class. The low N-Gain reflects the complexity of linking various concepts from different disciplines within a limited timeframe. In the STEM-ESD project, students were expected to connect scientific concepts regarding plastic materials and their properties, technological solutions for waste treatment, engineering design principles, and sustainability considerations including analysis, synthesis, and evaluation (Shejeena & Ismail, 2025). The time constraints of this project, which lasted only three sessions, may have limited students' ability to fully develop these interdisciplinary connections. This finding aligns with research conducted by Haćatrjana and Namsone (2024), who found that developing integrated understanding requires careful implementation and sufficient time for students to cultivate interdisciplinary thinking. These developments, though limited, indicate that STEM-ESD projects can foster interdisciplinary thinking when students are given the opportunity to connect ideas across subject areas (Lestari et al., 2025).

In terms of deep conceptual understanding, the experimental class achieved a low N-Gain of -0.21, while the control class achieved N-Gain of 0.15. Interestingly, the control class showed a significantly higher N-Gain value compared to the experimental class. These findings suggest that the discovery learning approach may be more effective in fostering deep conceptual understanding than the STEM-ESD approach in the context of this study. The shift in students' understanding from macroscopic to microscopic levels indicates that hands-on engagement with plastic waste materials may facilitate deeper understanding of underlying mechanisms. As noted by Mulyaningrum et al. (2025), developing deep conceptual understanding requires sustained engagement and structured support, which may not have been fully achieved within the constraints of this study. The limited improvement also reflects that students required more time to master complex scientific concepts related to polymer chemistry and environmental science, particularly when they were simultaneously managing multiple project tasks (Yulianto et al., 2025).

Students' sustainability actions defined as the translation of environmental knowledge and values into concrete, responsible behaviors addressing sustainability challenges (Hossain et al., 2025). Sustainability action represents a critical dimension of education that extends beyond knowledge acquisition to encompass behavioral change and environmentally conscious decision-making (Sass et al., 2025).

Normality test was conducted in the sustainability action indicator shown in Table 6. All data showed significance values greater than 0.05, indicating normal distribution.

Table 6. Normality test results on sustainability action

Data	Normality test
Pre-test	
Experiment	0.924
Post-test Control	0.199

Post-test	
Experiment	0.301
Post-test Control	0.872

Based on Table 7, the significance values for both the pre-test and post-test were greater than 0.05, indicating that the two classes had homogeneous variances. These results confirm that the assumptions of normality and homogeneity are met, thus allowing the use of parametric tests.

Table 7. Homogeneity test results on sustainability action

Data	Homogeneity test
Pre-test	0.873
Post-test	0.287

The independent t-test was measured after homogeneity test measured. Table 8 are shown.

Table 8. Descriptive analysis test of sustainability action

Data type	Pre-test		Post-test	
Class	Experiment	Control	Experiment	Control
Mean	2.64	2.74	2.71	2.83
Standard Deviation	0.24	0.23	0.21	0.26
Independent t-test	0.116		0.272	

Based on the Table 8, the pre-test analysis showed no significant difference between the experimental class and the control class post-test analysis also showed no significant difference. Both classes showed minimal improvement in sustainability actions.

Table 9. N-Gain analysis of sustainability action

Data	N-Gain	Category
Experiment	0.11	Low
Control	0.10	Low

Based on Table 9, both classes achieved very low N-gain, indicating minimal improvement in sustainability actions regardless of treatment.

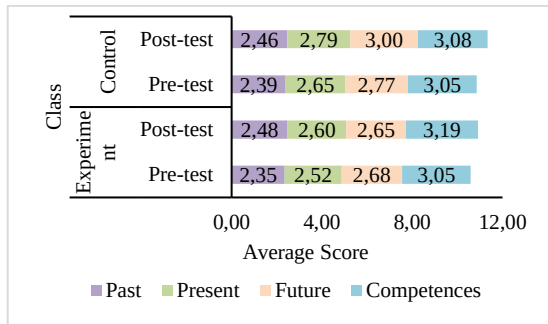


Figure 3. Students' scores per sustainability action indicator

Both classes showed minimal improvements across all sustainability action indicators, with all changes falling into the low N-Gain category. The experimental class showed slight increase in past and present actions, while both classes showed slight increases in future actions and competences.

The minimal increase in sustainable actions in both classes can be attributed to several key factors. One of these is that the relatively short duration of the project was insufficient to produce observable behavioral changes. As noted by Zhang and Cao (2025), education-mediated pro-environmental behavior does not occur directly but requires a deliberate approach to build attitudes and subjective norms among students. The Values-Beliefs-Norms theoretical framework explains that sustainable actions emerge when personal values trigger awareness of consequences, leading to a sense of responsibility, which ultimately translates into intentions and behavior (Castillo et al., 2024). This process takes time and may not be fully realized in a short-term intervention.

Measuring sustainability behaviors through questionnaires may not fully capture the complexity of behavioral change and is susceptible to social desirability bias, in which students may overestimate their environmentally friendly behaviors (Hadjichambis & Paraskeva-Hadjichambi, 2020). Additionally, students in the experimental class were not yet accustomed to the STEM-ESD model, which is a new pedagogical approach. This unfamiliarity may lead to an adjustment period during which students need time to adapt to the new learning structure, which could potentially limit the effectiveness of the intervention in

the short term (Fathurohman et al., 2023; Zarkasyi et al., 2024). Research by Rahal et al. (2026) found that sustained internalization of pro-environmental behaviors requires long-term engagement, while Linder et al. (2022) noted that past actions are more influenced by long-term environmental socialization than by short-term interventions.

The discovery learning approach used in the control class emphasized a transformative learning experience that connected knowledge to real-world contexts, which may have had a positive influence on the students' sustainability-related actions (Zebua et al., 2025). The discovery-based learning approach encourages students to develop competencies and take action based on their understanding through systematic observation and active engagement with the learning material (Pratiwi et al., 2025). Students in the control class continued to learn within the discovery learning framework they were already familiar with, allowing them to focus their cognitive resources on mastering the material, which may explain why the control class showed a slightly higher improvement on some indicators. These findings suggest that STEM-ESD projects are not sufficient to drive significant behavioral change in the short term. Sustainable behavioral change requires longer-term interventions involving repeated practice, sustained engagement, and commitment mechanisms (Alonso-Paulí et al., 2025).

CONCLUSION

The STEM-ESD project on plastic waste showed a positive but not statistically significant increase in students' integrative knowledge compared to discovery learning. The experimental class showed a moderate increase in contextual saliency, indicating that direct engagement with real-world problems may help students understand the relevance of knowledge. However, students' unfamiliarity with the STEM-ESD model required an adaptation period that reduced its immediate impact. This project resulted in minimal improvements in sustainability practices in both classes, as the short project

duration was insufficient to bring about behavioral change, the questionnaire was prone to social desirability bias, and students needed more time to internalize sustainability values.

This study contributes to the growing literature on the implementation of STEM-ESD in Indonesian schools by demonstrating that such projects show potential in fostering interdisciplinary understanding but are insufficient to drive significant behavioral change in the short term. These findings underscore the critical need for sustained, long-term interventions involving repeated practice to achieve meaningful, lasting outcomes.

REFERENCES

- Ajzen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
- Alonso-Paulí, E., Balart, P., Ezquerro, L., & Hernandez-Arenaz, I. (2025). Using Pledges to Improve the Effectiveness of Environmental Information Campaigns: The Case of Biowaste Recycling. *Proceedings of the National Academy of Sciences*, 122(18), e2414578122. <https://doi.org/10.1073/pnas.2414578122>
- Annisa, D. P., Kaniawati, I., & Eliyawati, E. (2024). STEM ESD-Based Learning with “Arduino Uno-Based Trash Can” to Improve Students’ Critical Thinking Skills and Sustainable Awareness in Learning Environmental Pollution. *Jurnal Penelitian Dan Pembelajaran IPA*, 10(1), 115. <https://doi.org/10.30870/jppi.v10i1.24008>
- Aziza, F., Lisa, Karima, R. F., & Hayaty, S. (2024). Pembelajaran Terintegrasi di SMP: Menghubungkan Disiplin Ilmu Dan Membentuk Pemahaman Holistik. *Interdisciplinary Explorations in Research Journal*, 2(1), 18–25. <https://doi.org/10.62976/ierj.v2i1.345>
- Bauer, M., & Morlock, G. E. (2025). Sustainable Schools: Changing Society towards Sustainability. *Sustainable Development*, 34(S1), 557–571. <https://doi.org/10.1002/sd.70184>
- Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities*. National Science Teachers Association.
- Campbell, C., & Speldewinde, C. (2022). Early Childhood STEM Education for Sustainable Development. *Sustainability*, 14(6), 3524. <https://doi.org/10.3390/su14063524>
- Capili, B., & Anastasi, J. K. (2024). An Introduction to Types of Quasi-Experimental Designs. *AJN, American Journal of Nursing*, 124(11), 50–52. <https://doi.org/10.1097/01.NAJ.0001081740.74815.20>
- Cardoso, G. C., Novaes, A. L., & Sabonaro, D. Z. (2025). Educação Para o Desenvolvimento Sustentável: Integração De Competências Técnicas e Habilidades Comportamentais Nas Disciplinas CTM: Português [Education for Sustainable Development: Integrating Technical Competencies and Behavioral Skills into STEM Subjects: Portuguese]. *Revista Brasileira de Educação Ambiental (RevBEA)*, 20(6), 54–74. <https://doi.org/10.34024/revbea.2025.v20.20258>
- Castillo, P. J. M., Cruz, R. L., & Martínez, D. S. (2024). Sustainability behaviors. An application of the VBN theory in engineering students. *Región Científica*, 3(1), 2024259. <https://doi.org/10.58763/c2024259>
- Coletta, V. P. (2023). Evidence for a Normal Distribution of Normalized Gains. *Physical Review Physics Education Research*, 19(1), 010111. <https://doi.org/10.1103/PhysRevPhysEduRes.19.010111>
- Coutts, E., Yorke, A., & Mower, T. (2022). An Integrated Approach to STEM and Sustainability Education within the New Zealand Context. *DS 117: Proceedings of the 24th International*

- Conference on Engineering and Product Design Education (E&PDE 2022), London South Bank University in London, UK. 8th - 9th September 2022. 24th International Conference on Engineering and Product Design Education.*
<https://doi.org/10.35199/EPDE.2022.118>
- Darmawan, M. S., Daeni, F., Kurniawan, T. S., & Listiaji, P. (2022). Preparation and Characterization of Edible Straw Made from Dragon Fruit Peel to Solve The Problem of Plastic Waste. *Journal of Environmental and Science Education*, 2(2), 106–110.
<https://doi.org/10.15294/jese.v2i2.60717>
- Dey, A., Dhumal, C. V., Sengupta, P., Kumar, A., Pramanik, N. K., & Alam, T. (2021). Challenges and Possible Solutions to Mitigate the Problems of Single-Use Plastics Used for Packaging Food Items: A Review. *Journal of Food Science and Technology*, 58(9), 3251–3269. <https://doi.org/10.1007/s13197-020-04885-6>
- English, L. D. (2016). STEM Education K-12: Perspectives on Integration. *International Journal of STEM Education*, 3(1), 3, s40594-016-0036–1.
<https://doi.org/10.1186/s40594-016-0036-1>
- Fathurohman, I., Amri, M. F., Septiyanto, A., & Riandi. (2023). Integrating STEM Based Education for Sustainable Development (ESD) to Promote Quality Education: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, 9(11), 1052–1059.
<https://doi.org/10.29303/jppipa.v9i11.4430>
- Hačatrjana, L., & Namsone, D. (2024). Breaking Down the Concept of Students' Thinking and Reasoning Skills for Implementation in the Classroom. *Journal of Intelligence*, 12(11), 109.
<https://doi.org/10.3390/jintelligence12110109>
- Hadjichambis, A. Ch., & Paraskeva-Hadjichambi, D. (2020). Environmental Citizenship Questionnaire (ECQ): The Development and Validation of an Evaluation Instrument for Secondary School Students. *Sustainability*, 12(3), 821. <https://doi.org/10.3390/su12030821>
- Hake, R. R. (1998). Interactive-Engagement versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Sources. *American Journal of Physics*, 66(1), 64–74.
<https://doi.org/10.1119/1.18809>
- Heiges, J., Lee, D. L., Vollmer, L., Wobbekind, K., Thompson, H. R., Gosliner, W., Madsen, K. A., O'Neill, K., & Ritchie, L. D. (2022). Evaluating Food Packaging Waste in Schools: A Systematic Literature Review. *International Journal of Environmental Research and Public Health*, 19(9), 5607.
<https://doi.org/10.3390/ijerph19095607>
- Hermawan, M., Heriyati, P., & Andrew, N. (2021). Exploring Program on Ocean Plastic Pollution Management: Case of NGO in Jakarta. *IOP Conference Series: Earth and Environmental Science*, 729(1), 012122.
<https://doi.org/10.1088/1755-1315/729/1/012122>
- Hossain, M. I., Jamadar, Y., Islam, M. F., Rashed, Md., & Akter, T. (2025). Environmental Sustainability Practices in SMEs: Insights from Integrated PLS-SEM and fsQCA Approaches. *Journal of Cleaner Production*, 503, 145185.
<https://doi.org/10.1016/j.jclepro.2025.145185>
- Indriani, Y., Tunggal Dewi, T. T., Bilqinaristi, C., Ainnurochimah, H. I., & Lukita Cahyani, T. R. (2025). Edukasi Kreatif Pengolahan Limbah Botol menjadi Pot Bunga sebagai Upaya Peningkatan Kesadaran Lingkungan di SDN Jari 2. *Jurnal Pengabdian Masyarakat (ABDIRA)*, 5(4), 164–171.
<https://doi.org/10.31004/abdira.v5i4.971>
- Ivasyk, V., & Voytovych, A. (2025). Development of Learning Motivation in Primary Education Students through Integrated Learning. *Visnyk of Lviv University. Series Pedagogics*, (42), 137–148.
<https://doi.org/10.30970/vpe.2025.42.13464>

- KLH-BPLH. (2025, June 22). *KLH-BPLH Tegaskan Arah Baru Menuju Indonesia Bebas Sampah 2029 dalam Rakornas Pengelolaan Sampah 2025*. Kementerian Lingkungan Hidup/Badan Pengendalian Lingkungan Hidup. <https://www.kemenlh.go.id/news/detail/klh-bplh-tegaskan-arab-baru-menuju-indonesia-bebas-sampah-2029-dalam-rakornas-pengelolaan-sampah-2025>
- Lestari, M. F., Saihan, S., & Usriyah, L. (2025). SLR Study: Plastic Waste Recycling Innovation as a Science Learning Medium in Elementary Schools. *JENIUS (Journal of Education Policy and Elementary Education Issues)*, 6(2), 135–144. <https://doi.org/10.22515/jenius.v6i2.11287>
- Linarti, U., Jamilatun, S., & Nihanzah, A. S. P. (2025). Penguatan Pembelajaran Bidang STEM Melalui Pemanfaatan Limbah Plastik Menjadi Ecobrick di SMK Tengku Afzan Kuantan, Malaysia. *Jurnal SOLMA*, 14(2), 2472–2479. <https://doi.org/10.22236/solma.v14i2.18662>
- Linder, N., Giusti, M., Samuelsson, K., & Barthel, S. (2022). Pro-environmental Habits: An Underexplored Research Agenda in Sustainability Science. *Ambio*, 51(3), 546–556. <https://doi.org/10.1007/s13280-021-01619-6>
- Littaqwa, L. A., Hadi, T., Rancak, G. T., & Safwanudin, S. (2025). Analisis Timbulan dan Komposisi Sampah Sekolah Dasar (SD) di Kota Mataram. *Nata Palemahan: Journal of Environmental Engineering Innovations*, 2(2), 56–63. <https://doi.org/10.38043/natapalemahan.v2i2.6628>
- Liu, Z., Pan, S., Zhang, X., & Bao, L. (2022). Assessment of Knowledge Integration in Student Learning of Simple Electric Circuits. *Physical Review Physics Education Research*, 18(2), 020102. <https://doi.org/10.1103/PhysRevPhysEduRes.18.020102>
- Maitlo, G., Ali, I., Maitlo, H. A., Ali, S., Unar, I. N., Ahmad, M. B., Bhutto, D. K., Karmani, R. K., Naich, S. U. R., Sajjad, R. U., Ali, S., & Afridi, M. N. (2022). Plastic Waste Recycling, Applications, and Future Prospects for a Sustainable Environment. *Sustainability*, 14(18), 11637. <https://doi.org/10.3390/su141811637>
- Muliakoswara, M. H., Kaniawati, I., & Suwarma, I. R. (2024). Implementation of STEM-ESD Learning in Improving Critical Thinking Skills in Renewable Energy Material. *WaPFI (Wahana Pendidikan Fisika)*, 9(2), 121–130. <https://doi.org/10.17509/wapfi.v9i2.66656>
- Mulyaningrum, V. D., Sajiman, S. U., & Hasbullah, H. (2025). Transforming Chemistry Learning through Deep Learning: An Evaluation with CIPP Model. *Prima Magistra: Jurnal Ilmiah Kependidikan*, 7(1), 116–124. <https://doi.org/10.37478/jpm.v7i1.5855>
- Nagatomo, D. (2024). Research on Education for Sustainable Development with Design-Based Research by Employing Industry 4.0 Technologies for the Issue of Single-Use Plastic Waste in Taiwan. *Sustainability*, 16(22), 9832. <https://doi.org/10.3390/su16229832>
- Parejo, J.-L., Corton-Heras, M.-O., Nieto-Blanco, A., & Segovia-Barberan, C. (2021). Plastics as an Educational Resource for Sustainable Development: A Case Study in Ghana. *Sustainability*, 13(12), 6727. <https://doi.org/10.3390/su13126727>
- Pratiwi, H. D., Putri, R. E., & Yenira, F. (2025). Upaya Meningkatkan Hasil Belajar Siswa melalui Penggunaan Model Pembelajaran Discovery Learning pada Mata Pelajaran IPA SMP. *TSAQOFAH: Jurnal Penelitian Guru Indonesia*, 5(3), 2853–2861. <https://doi.org/10.58578/tsaqofah.v5i3.6020>
- Purwaningrum, P. (2016). Upaya Mengurangi Timbulan Sampah Plastik di Lingkungan. *Indonesian Journal of Urban and Environmental Technolog*, 8(2), 141–147.

- <https://doi.org/10.25105/urbanenvirotech.v8i2.1421>
- Putra, M. N. A., Zahrani, N. A., Az Zahra, T., Hariyadi, A. G., Abiyyu, S. A. A., Justicio, M. N., & Firmansyah, P. (2024). Sampah Plastik sebagai Ancaman terhadap Lingkungan. *Aktivisme: Jurnal Ilmu Pendidikan, Politik Dan Sosial Indonesia*, 2(1), 154–165. <https://doi.org/10.62383/aktivisme.v2i1.725>
- Rahal, S., Alzubi, A., & Iyiola, K. (2026). How Sustainability Orientation Drives Pro-Environmental Behavior in Entrepreneurial Firms: The Roles of Social Support and Sustainable Entrepreneurship. *Sustainability*, 18(4), 2113. <https://doi.org/10.3390/su18042113>
- Sass, W., Boeve-de Pauw, J., Olsson, D., Rieckmann, M., & Gericke, N. (2025). A Quality Education for Sustainability Teaching (QUEST) Framework: Advancing Action Competence in Sustainability Education. *The Journal of Environmental Education*, 56(6), 417–434. <https://doi.org/10.1080/00958964.2025.2542937>
- Shejeena, K. A., & Ismail, T. (2025). Connecting Ideas in Science Education: Enhancing Secondary Students' Learning through Knowledge Integration. *Journal on School Educational Technology*, 21(2), 15. <https://doi.org/10.26634/jsch.21.2.22383>
- UNESCO. (2017). Education for Sustainable Development Goals: Learning Objectives. UNESCO. <https://doi.org/10.54675/CGBA9153>
- United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. United Nations. <https://sdgs.un.org/2030agenda>
- Weng, X., Cui, Z., Ng, O.-L., Jong, M. S. Y., & Chiu, T. K. F. (2022). Characterizing Students' 4C Skills Development During Problem-based Digital Making. *Journal of Science Education and Technology*, 31(3), 372–385. <https://doi.org/10.1007/s10956-022-09961-4>
- Widodo, A. (2021). *Pembelajaran Ilmu Pengetahuan Alam* (Vol. 53). UPI Pres.
- Ye, D., Qian, J., Xu, W., Lu, Y., Wang, S., Xiao, L., & Bao, L. (2024). Assessment of Knowledge Integration in Student Learning of Galvanic Cell: An Interdisciplinary Approach Connecting Physics and Chemistry. *Physical Review Physics Education Research*, 20(2), 020129. <https://doi.org/10.1103/PhysRevPhysEduRes.20.020129>
- Yulianto, A., Pramono, S. E., Wijaya, A. P., Lestari, S., & Putit, L. (2025). Examining the Effects of Task Complexity and Task Difficulty on Students' Knowledge Retention: A Cognitive Load Theory Perspective. *Jurnal Kependidikan : Jurnal Hasil Penelitian Dan Kajian Kepustakaan Di Bidang Pendidikan, Pengajaran, Dan Pembelajaran*, 11(4), 1347–1358. <https://doi.org/10.33394/jk.v11i4.18326>
- Zadorozhna, O., Mordous, I., & Revin, F. (2024). STEM As an Integral Part the Science Education Curriculum. *Актуальні Питання у Сучасній Науці*, (8(26)). [https://doi.org/10.52058/2786-6300-2024-8\(26\)-748-758](https://doi.org/10.52058/2786-6300-2024-8(26)-748-758)
- Zarkasyi, M. H., Abidin, Z., & Praherdhiono, H. (2024). Beban Kognitif Siswa Dalam Pembelajaran Berdasarkan Kurikulum Merdeka Sekolah Dasar. *Journal of Educational Technology Studies and Applied Research*, 1(2). <https://doi.org/10.70125/jetsar.v1i2y2024a18>
- Zebua, H. I. P., Telaumbanua, A., Harefa, E. B., & Telaumbanua, A. (2025). Pengaruh Model Discovery Learning terhadap Hasil Belajar Siswa pada Materi Sustainable Building. *Arus Jurnal Sosial Dan Humaniora*, 5(2), 2701–2707. <https://doi.org/10.57250/ajsh.v5i2.1528>
- Zhang, J., & Cao, A. (2025). The Psychological Mechanisms of Education for Sustainable Development: Environmental Attitudes, Self-Efficacy, and Social Norms as Mediators of Pro-Environmental Behavior among University Students.

Sustainability, 17(3), 933.
<https://doi.org/10.3390/su17030933>