15 (2) (2026) 279-285

Unnes Science Education Journal

Accredited Sinta 2

https://journal.unnes.ac.id/journals/usej

Developing STEM Literacy through Interdisciplinary Learning on Environmental Change

Dida Firgiawan, Ari Widodo✉, Riandi Riandi, Sri Angraeni

DOI: http://dx.doi.org/10.15294/usej.v115i2.44613

Universitas Pendidikan Indonesia, Indonesia

Article Info

Submitted 2026-03-27
Revised 2026-04-27
Accepted 2026-08-29

Keywords

Environmental Change; ESD; Interdisciplinary STEM; STEM Literacy; Sustainability Education

Abstract

This study aimed to develop and evaluate an interdisciplinary STEM learning model integrated with Education for Sustainable Development to enhance senior high school students' STEM literacy on environmental change topics. A mixed-methods approach with a quasi-experimental pretest–posttest control group design was employed, supported by qualitative analysis of students' learning processes. Quantitative data were collected using a validated 24-item test measuring four dimensions of STEM literacy science, technology, engineering, and mathematics and analyzed using comparative statistics and normalized gain. Qualitative data were analyzed thematically to examine students' systemic understanding. The results showed that the experimental group achieved higher improvement (mean pretest = 60.88; posttest = 93.39; normalized gain = 0.86, high) compared to the control group (mean pretest = 59.02; posttest = 85.87; normalized gain = 0.69, moderate). Across the four STEM literacy dimensions, the experimental group reached the high category on science (0.86), technology (0.89), engineering (0.81), and mathematics (0.75), whereas the control group reached the high category only on engineering (0.74) and remained in the moderate category on science (0.57), technology (0.68), and mathematics (0.59). It can be concluded that integrating Education for Sustainable Development into interdisciplinary STEM learning effectively enhances students' holistic STEM literacy and supports sustainability-oriented science learning.

How to Cite

Firgiawan, D., Widodo, A., Riandi, R., & Angraeni, R. S. (2026). Developing STEM Literacy through Interdisciplinary Learning on Environmental Change. *Unnes Science Education Journal*, 15(2), 279-285.

✉ Correspondence Author:
E-mail: ari_widodo@upi.edu

p-ISSN 2252-6617

INTRODUCTION

The increasing complexity of global challenges, including environmental degradation, biodiversity loss, pollution, and resource scarcity, has become a critical concern worldwide, including in Indonesia. These interconnected issues are largely driven by human activities and rapid technological development, requiring integrated and multidisciplinary solutions (Segara, 2015; United Nations, 2015). Addressing such complex problems demands individuals who are able to connect knowledge across disciplines and apply scientific understanding in real-world contexts.

Education plays a crucial role in preparing learners to respond to these challenges. In the context of sustainability, education is expected not only to transmit knowledge but also to develop competencies enable students to design innovative and responsible solutions (UNESCO, 2017; OECD, 2018). One relevant framework is Education for Sustainable Development (ESD), which promotes the integration of environmental, social, and economic perspectives and encourages systems thinking and long-term decision making (Rieckmann, 2018). However, sustainability issues inherently require interdisciplinary approaches go beyond single-subject learning.

Interdisciplinary learning integrates concepts and perspectives from different disciplines into coherent learning experiences centered on real-world problems (Helmane & Briska, 2017). Within this context, Science, Technology, Engineering, and Mathematics (STEM) education provides a strong pedagogical framework that emphasizes problem solving, innovation, and integration of knowledge and skills (Kelley & Knowles, 2016). One of the main goals of STEM education is to develop STEM literacy, defined as ability to apply and integrate knowledge science, technology, engineering, and mathematics to understand solve complex problems (Bybee, 2013).

Conceptually, STEM and ESD have complementary orientations. STEM focuses on interdisciplinary problem solving, while ESD emphasizes sustainability values and systemic perspectives. The integration of both approaches has potential to promote meaningful learning experiences connect scientific understanding with real-world sustainability challenges (Wiek et al., 2016). Previous studies tend to implement ESD within single disciplines or focus STEM learning on technical product development rather than fostering integrated understanding of environmental systems (Thibaut et al., 2018; Wahono et al., 2020). This indicates a gap in research on integration of interdisciplinary STEM and ESD to enhance students' STEM literacy, particularly in environmental change contexts.

Empirical evidence on integrating STEM and ESD remains mixed. Controlled interventions show that systems-thinking tools embedded in STEM simulations can improve students' understanding of a sustainability problem, yet such tools are rarely paired with validated instruments to confirm that the STEM dimensions themselves are strengthened (Green, Molloy, & Duggan, 2022). Likewise, longitudinal evidence indicates that ESD interventions delivered in isolation from a disciplinary problem-solving structure tend to produce only modest and inconsistent gains in students' action competence for sustainability (Olsson, Gericke, & Boeve-de Pauw, 2022).

In contrast, interdisciplinary STEM instruction that requires students to apply concepts from several subjects within one authentic task has been shown to significantly raise STEM literacy scores, indicating that success depends on deliberate task design rather than mere thematic overlap between subjects (Fang, Hsu, & Lin, 2019). Reviews of integrated STEM implementation further show that the most successful models rely on sustained cross-subject teacher collaboration, which is difficult to sustain when ESD content is appended to an existing STEM curriculum instead of being co-designed with it (Kelley, Knowles, Han, & Trice, 2021). In Indonesia specifically, scoping and systematic reviews report that STEM implementation is still constrained by teachers' limited conceptual understanding of integration and by inadequate learning facilities, while explicit incorporation of sustainability content across disciplines remains rare (Cahyanti et al., 2024; Farwati et al., 2021). Teachers themselves report favorable attitudes toward STEM for sustainable development but limited practical guidance on how to operationalize it across subjects (Rahman, Kaniawati, Riandi, & Hendayana, 2023). Taken together, these findings suggest that the central challenge is not whether STEM and ESD are conceptually compatible, but how their integration can be operationalized so that sustainability content strengthens, rather than dilutes, students' STEM literacy.

This challenge is particularly pressing given the empirical condition of STEM literacy among Indonesian students. National results from the Programme for International Student Assessment (PISA) 2022 show that Indonesian 15-year-old students achieved an average science score of 383, well below the OECD average of 485, with a similarly wide gap in mathematics

(OECD, 2023). These outcomes mirror systemic constraints identified in Indonesian STEM education research, including limited laboratory facilities, uneven access to technology, and insufficient teacher training in designing cross-disciplinary instruction (Cahyanti et al., 2024; Farwati et al., 2021). Within this context, environmental change is a curriculum topic in which students are frequently found to memorize causes and impacts without connecting them to feasible technological solutions or to the social and economic trade-offs involved in addressing them, limiting the topic's potential to build integrated STEM literacy.

From an applied standpoint, integrating disciplines beyond Science, Technology, Engineering, and Mathematics into a single instructional unit is not straightforward within the Indonesian senior high school system. Subjects such as Biology, Sociology, and Economics are typically taught separately by different teachers within fixed weekly schedules that leave little dedicated time for cross-subject planning or co-teaching, even though the Merdeka Curriculum's project-based strengthening of the Pancasila Student Profile (P5) formally opens space for such integration. In practice, many teachers report that they lack concrete models for translating this policy flexibility into a coherent interdisciplinary lesson sequence, so that environmental projects conducted under P5 activities are sometimes reduced to poster-making or awareness campaigns that do not require the same scientific and mathematical reasoning as a full STEM engineering task, leaving the policy's intended STEM literacy outcomes largely unrealized. Environmental change was selected as the context for this study because it is a mandatory Biology topic that directly touches students' everyday environment while also naturally inviting economic questions, such as the cost and feasibility of mitigation technologies, and social questions, such as equitable access to clean resources, thereby providing a concrete, curriculum-anchored entry point for interdisciplinary STEM–ESD instruction rather than an artificially constructed topic.

Given this empirical and applied gap, this study aims to develop and evaluate an interdisciplinary STEM learning approach integrated with Education for Sustainable Development to enhance senior high school students' STEM literacy on environmental change topics. Specifically, this study investigates whether the interdisciplinary STEM–ESD approach improves students' STEM literacy and examines differences in learning outcomes compared to conventional STEM learning.

METHOD

This study employed a mixed-methods approach using an embedded quasi-experimental design, in which quantitative data were prioritized and supported by qualitative data to enrich interpretation (Creswell & Plano Clark, 2018). The quantitative component applied a non-equivalent control group pretest-posttest design to examine effectiveness of interdisciplinary STEM learning approach integrated Education for Sustainable Development in improving students' STEM literacy. This design was selected because intact classroom groups were used, making random assignment impractical (Fraenkel et al., 2012).

The participants were 72 tenth-grade students from a public senior high school in Bandung, Indonesia, selected through purposive sampling. Two intact classes were assigned as an experimental group (n = 36) and a control group (n = 36). Both groups were taught the same topic, environmental change, by the same teacher to control instructional variability.

The instructional intervention was developed using the ADDIE model (Branch, 2009), which includes analysis, design, development, implementation, and evaluation stages. The experimental group received interdisciplinary STEM–ESD instruction integrating Biology, Sociology, and Economics through a project-based activity involving the design of a solar-powered water purification system. In contrast, the control group received conventional STEM instruction without explicit interdisciplinary integration or sustainability orientation. The interdisciplinary project was implemented over a three-week instructional period comprising four classroom sessions of 3 × 45 minutes each, during which students sequentially engaged with the scientific and engineering design of the water purification system, an economic feasibility analysis of the proposed solution, and a sociological analysis of community access to clean water.

Data were collected using a 24 item validated multiple-choice test measuring four dimensions STEM literacy. Content validity was evaluated by experts, and reliability testing acceptable internal consistency (Cronbach's alpha>0.70). Qualitative data were obtained through classroom observations to capture students' engagement and application STEM concepts.

Data collection procedures included pretest, intervention, and posttest stages. Students' learning improvement was analyzed using normalized gain (Hake, 1999). Statistical analysis employed the Wilcoxon signed-rank test to examine within-group differences and the Mann–Whitney U test to compare between groups. Non-parametric tests were used based on data distribution, with a significance level of 0.05.

RESULT AND DISCUSSION

The results showed that students' STEM literacy improved in both groups; however, the improvement in the experimental group was significantly higher than in the control group.

Table 1. Descriptive Statistics and Hypothesis Test Results for the Experimental and Control Groups

Data Type		Pretest		Posttest	
Group		**Experimental**	**Control**	**Experimental**	**Control**
N		36	36	36	36
Highest score		75.00	75.00	100.00	100.00
Lowest score		37.48	37.48	83.30	66.68
Mean		60.88	59.02	93.39	85.87
Standard deviation		11.50	12.18	7.29	10.02
Gain		Experimental 32.51		Control 26.85	
N-Gain		Experimental 0.86 (High)		Control 0.69 (Moderate)	
Normality test (Shapiro-Wilk)	Sig	0.0005	0.0043	0.0000015	0.0159
	Interpretation	Not normal	Not normal	Not normal	Not normal
Homogeneity test (Levene's test)	Sig	0.7786		0.2274	
	Interpretation	Homogeneous		Homogeneous	
Mann-Whitney U test	Sig	0.337		0.0011	
	Interpretation	Not significantly different		Significantly different	

Note: Sig. = significance value (p-value); N-Gain categories follow Hake (1998): High (g ≥ 0.7), Moderate (0.3 ≤ g < 0.7), Low (g < 0.3).

The experimental group achieved a mean score increase from 60.88 (pretest) to 93.39 (posttest), a gain of 32.51, with a normalized gain (N-Gain) of 0.86 (high category). The control group increased from a mean of 59.02 (pretest) to 85.87 (posttest), a gain of 26.85, with an N-Gain of 0.69 (moderate category). The experimental group also showed a smaller spread of scores at posttest (SD = 7.29) than the control group (SD = 10.02), indicating that the interdisciplinary STEM–ESD treatment produced not only a larger average gain but also a more consistent improvement across students. These findings indicate that the interdisciplinary STEM learning approach integrated with Education for Sustainable Development was more effective in enhancing students' STEM literacy than conventional STEM learning. This finding is consistent with previous studies reported in the Unnes Science Education Journal which show that STEM-based learning significantly improves students' scientific literacy and problem-solving skills (Wahono et al., 2018; Sari & Nuswowati, 2019).

Prior to the intervention, the Shapiro-Wilk test indicated that scores in both groups were not normally distributed (experimental: p = 0.0005; control: p = 0.0043), while Levene's test confirmed that the two groups' variances were homogeneous (p = 0.7786). Given the non-normal distribution, the non-parametric Mann–Whitney U test was used to compare the groups, and the result (p = 0.337) confirmed that the experimental and control groups began the intervention with comparable STEM literacy, ruling out prior ability as an explanation for the difference in outcomes that followed (see Table 1).

At posttest, scores in both groups again departed from normality (Shapiro-Wilk: experimental p = 0.0000015; control p = 0.0159), while variances remained homogeneous (Levene's test, p = 0.2274). The Mann–Whitney U test on posttest scores showed a statistically significant difference between the two groups (p = 0.0011), confirming that the experimental group's advantage after treatment was not attributable to chance. This pattern is consistent with a genuine treatment effect of the interdisciplinary STEM-ESD approach on students' overall STEM literacy, rather than an artifact of pre-existing differences between groups.

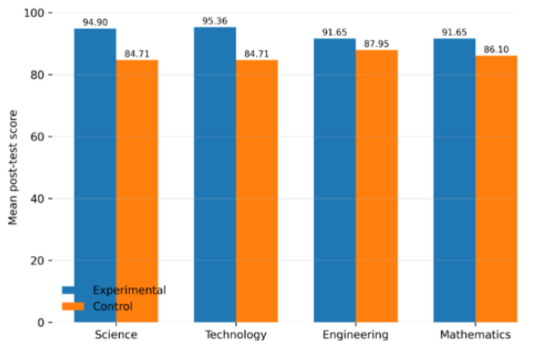

Figure 1. Comparison of Mean Post-Test Scores Across STEM Literacy Dimensions Between the Experimental and Control Groups

Table 2. Normalized gain (N-Gain) of STEM literacy aspects in the experimental and control groups

Aspect	Experimental Group (N-Gain)	Category	Control Group (N-Gain)	Category
Science	0.86	High	0.57	Moderate
Technology	0.89	High	0.68	Moderate
Engineering	0.81	High	0.74	High
Mathematics	0.75	High	0.59	Moderate

Figure 1 shows that the experimental group outperformed the control group on posttest scores across all four STEM literacy aspects: science (94.90 vs. 84.71), technology (95.36 vs. 84.71), engineering (91.65 vs. 87.95), and mathematics (91.65 vs. 86.10). This pattern was mirrored in the normalized gain scores, where the experimental group reached the high category on all four aspects (N-Gain 0.75-0.89), while the control group reached the high category only on engineering (N-Gain 0.74) and remained in the moderate category on science, technology, and mathematics (N-Gain 0.57-0.68). Notably, the largest experimental-control gap appeared in technology literacy, suggesting that the hands-on, iterative design work involved in building the solar-powered purification device gave students in the experimental group a distinct advantage in this dimension, one that a lecture-based conventional approach was less able to replicate. The relatively smaller gap in engineering literacy, where both groups reached the high N-Gain category, indicates that some engineering-related reasoning may transfer more readily to students even without an integrated project structure, an observation worth exploring further in future studies. Taken together, these results confirm that the benefit of the interdisciplinary STEM-ESD approach was not confined to a single disciplinary dimension but extended across science, technology, engineering, and mathematics reasoning alike.

This improvement can be explained by how the solar-powered water purification project was structured, rather than merely by the fact that it integrated multiple disciplines. Designing and testing the purification system required students to explain the underlying scientific principle of solar-driven evaporation and filtration (science), to select and justify appropriate materials and construction techniques (engineering and technology), and to calculate purification efficiency, cost, and output volume (mathematics) within a single iterative design cycle. Because these dimensions were required to solve one authentic problem rather than practiced as separate exercises, students could not strengthen one dimension in isolation; each design decision immediately created a reason to apply other three. This is consistent with evidence that integrated STEM programs succeed when disciplinary content is embedded within a shared authentic task and supported by deliberate cross-subject planning, rather than when disciplines are simply taught in parallel (Kelley, Knowles, Han, & Trice, 2021; Kelley & Knowles, 2016). It also aligns with findings that simulation- and systems-based sustainability tasks strengthen students' ability to apply technical concepts to real-world problems by making the consequences of design choices immediately visible and testable (Green, Molloy, & Duggan, 2022).

Furthermore, the incorporation of sustainability perspectives through Education for Sustainable Development enhanced the relevance of learning by connecting scientific knowledge with real-world environmental issues. Students were not only engaged in technical problem solving but also in evaluating environmental impacts and sustainability considerations. Such learning experiences foster systems thinking and support the development of holistic STEM literacy (Rieckmann, 2018). In addition, STEM-based environmental learning has been shown to enhance students' environmental literacy, particularly when sustainability contexts are explicitly integrated (Pratiwi & Supardi, 2020). This benefit, however, is most likely to be sustained when sustainability content is embedded within, rather than added onto, a disciplinary task, since ESD interventions delivered in isolation from a concrete problem-solving structure have been shown to produce only modest and inconsistent gains in students' action competence for sustainability (Olsson, Gericke, & Boeve-de Pauw, 2022).

In addition, the integration of multiple disciplines facilitated knowledge transfer across domains. Science concepts provided explanations of environmental phenomena, technology and engineering supported solution design, and mathematics enabled quantitative evaluation. This interaction strengthened students' ability to analyze problems comprehensively rather than in isolated disciplinary contexts. Previous studies have shown that interdisciplinary STEM learning improves students' ability to connect concepts and apply knowledge in authentic contexts (Thibaut et al., 2018). Compared to conventional STEM learning, which tends to focus on procedural and fragmented knowledge, the interdisciplinary STEM–ESD approach offered a more meaningful and contextual learning experience. This contributed to higher student engagement, better conceptual understanding, and improved learning outcomes.

Overall, the findings demonstrate that integrating interdisciplinary STEM learning with Education for Sustainable Development provides significant benefits in enhancing students' STEM literacy, particularly in environmental learning contexts. This approach offers a practical framework for developing sustainability-oriented competencies and preparing students to address complex real-world problems.

CONCLUSION

This study examined the effectiveness of an interdisciplinary STEM-ESD learning approach in improving senior high school students' STEM literacy on environmental change topics, and the findings demonstrate that this approach significantly enhances students' STEM literacy across all four dimensions science, technology, engineering, and mathematics with students who participated in interdisciplinary STEM–ESD learning achieving higher posttest scores and learning gains than those receiving conventional STEM instruction; these results confirm that integrating Biology, Sociology, and Economics within sustainability-based learning contexts creates more meaningful learning experiences and strengthens students' ability to apply STEM knowledge to real-world environmental problems, while the statistically significant difference observed between the experimental and control groups on both the overall STEM literacy score and each of the four dimensions further indicates that interdisciplinary integration combined with project-based sustainability activities contributes more effectively and more consistently to STEM literacy development than conventional STEM approaches. Theoretically, these findings provide empirical support for interdisciplinary STEM–ESD as an effective framework for fostering STEM literacy in secondary education, and practically, they suggest that STEM instruction should emphasize interdisciplinary collaboration and real-world sustainability challenges to promote functional and applicable STEM competencies; accordingly, future studies are recommended to explore broader implementation contexts and to examine the long-term impact of interdisciplinary STEM-ESD learning on students' STEM competencies.

Future research is recommended to expand the implementation of interdisciplinary STEM–ESD learning across different educational levels and subject domains to examine its broader applicability. Longitudinal studies are also needed to investigate the sustainability of students' STEM literacy development over time.

In addition, future studies may integrate digital technologies such as artificial intelligence, simulation tools, or data analytics to strengthen students' technological and engineering literacy components. Researchers are also encouraged to explore teacher professional development models that support interdisciplinary collaboration, as teacher readiness plays a critical role in successful STEM-ESD implementation.

From a practical perspective, educators and policymakers should consider embedding sustainability-based interdisciplinary projects into STEM curricula to promote authentic problem-solving skills aligned with 21st-century educational goals.

REFERENCES

Balka, D. S. (2011). *STEM education: A global perspective*. Information Age Publishing.

Brundiers, K., Wiek, A., & Redman, C. L. (2010). Real-world learning opportunities in sustainability. *International Journal of Sustainability in Higher Education,* 11(4), 308–324.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities.* NSTA Press.

Cahyanti, N. A., Suyanto, S., Wantara, N., Begimbetova, G. A., Uanayah, H., & Nur Khilafah, M. R. (2024). A systematic review of STEM education implementation in Indonesian high schools: Opportunities, challenges, and policy recommendations. *Jurnal Pendidikan MIPA*, 25(3), 1428–1443.

Clark, W. C., van Kerkhoff, L., Lebel, L., & Gallopin, G. C. (2017). Crafting usable knowledge for sustainable development. *Proceedings of the National Academy of Sciences*, 113(17), 4570–4578.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253–260.

Depdiknas. (2003). Undang-undang Republik Indonesia Nomor 20 Tahun 2003 tentang Sistem Pendidikan Nasional. Departemen Pendidikan Nasional.

Dunlap, R. E. (2002). Paradigms, theories and environmental sociology. In R. E. Dunlap & W. Michelson (Eds.), Handbook of environmental sociology (pp. 329–350). Greenwood Press.

English, L. D. (2016). STEM education K–12: Perspectives on integration. *International Journal of STEM Education,* 3(3), 1–8.

English, L. D. (2023). Advancing STEM literacy through interdisciplinary problem solving. *International Journal of STEM Education*, 10(12), 1–15.

Fang, S. C., Hsu, Y. S., & Lin, S. S. (2019). Developing STEM literacy through interdisciplinary learning. *Eurasia Journal of Mathematics, Science and Technology Education*, 15(6), 1–15.

Farwati, R., Metafisika, K., Sari, I., Sitinjak, D. S., Solikha, D. F., & Solfarina, S. (2021). STEM education implementation in Indonesia: A scoping review. *International Journal of STEM Education for Sustainability*, 1(1), 11–32.

Gardner, H. (2006). *Five minds for the future*. Harvard Business School Press.

Green, C., Molloy, O., & Duggan, J. (2022). An empirical study of the impact of systems thinking and simulation on sustainability education. *Sustainability*, 14(1), 394.

Helmane, I., & Briska, I. (2017). What is developing integrated or interdisciplinary or multidisciplinary or transdisciplinary education in school? *Signum Temporis*, 9(1), 7–15.

Hiller, S. E., Kitsantas, A., & Poulos, A. (2020). The impact of environmental project-based learning on students' scientific literacy. *Journal of Research in Science Teaching,* 57(8), 1235–1258.

Holmlund, T. D., Lesseig, K., & Slavit, D. (2018). Making sense of STEM education in K–12 contexts. *International Journal of STEM Education,* 5(32), 1–18.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education,* 3(11), 1–11.

Kelley, T. R., Knowles, J. G., Han, J., & Trice, A. N. (2021). Integrated STEM models of implementation. *Journal of STEM Education: Innovations and Research*, 22(1), 34–45.

Klein, J. T., & Newell, W. H. (1997). Advancing interdisciplinary studies. In J. T. Klein & W. H. Newell (Eds.), Interdisciplinarity: Essays from the literature (pp. 3–22). College Entrance Examination Board.

Leicht, A., Heiss, J., & Byun, W. J. (Eds.). (2018). *Issues and trends in education for sustainable development.* UNESCO Publishing.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K–12 STEM education. *Journal of Pre-College Engineering Education Research*, 4(1), 1–13.

Murfiah, U. (2017). *Pembelajaran terpadu: Konsep dan implementasi.* Refika Aditama.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

National STEM Education Center. (2014). *STEM education framework.* National STEM Centre.

OECD. (2018). *PISA 2018 assessment and analytical framework*. OECD Publishing.

OECD. (2019). *PISA 2018 results (Volume I): What students know and can do*. OECD Publishing.

OECD. (2023). *PISA 2022 results (Volume I): The state of learning and equity in education.* OECD Publishing.

Olsson, D., Gericke, N., & Boeve-de Pauw, J. (2022). The effectiveness of education for sustainable development revisited: A longitudinal study on secondary students' action competence for sustainability. *Environmental Education Research*, 28(3), 405–429.

Pratiwi, U., & Supardi, K. I. (2020). STEM-based learning to enhance students' environmental literacy. *Unnes Science Education Journal,* 9(1), 1–8.

Rahman, A. A., Kaniawati, I., Riandi, R., & Hendayana, S. (2023). Secondary science teachers' perception on STEM learning for sustainable development. *Jurnal Penelitian Pendidikan IPA*, 9(3), 1297–1303.

Rieckmann, M. (2018). *Learning to transform the world: Key competencies in education for sustainable development.* UNESCO Publishing.

Sari, D. P., & Nuswowati, M. (2019). The implementation of STEM approach to improve students' problem-solving skills. *Unnes Science Education Journal,* 8(2), 145–152.

Segara, N. B. (2015). Education for sustainable development (ESD): Sebuah upaya mewujudkan kelestarian lingkungan. *Jurnal Sosial Humaniora,* 8(1), 22–30.

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018). The influence of teachers' attitudes and school context on STEM implementation. *International Journal of Science and Mathematics Education*, 16(1), 1–21.

UNESCO. (2012). *Shaping the education of tomorrow: 2012 report on the UN decade of education for sustainable development.* UNESCO Publishing.

UNESCO. (2017). *Education for sustainable development goals: Learning objectives.* UNESCO Publishing.

UNESCO. (2020). *Education for sustainable development: A roadmap.* UNESCO Publishing.

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development.* United Nations.

Wahono, B., Nurhayati, S., & Widodo, W. (2018). The effectiveness of STEM-based learning on students' scientific literacy. *Unnes Science Education Journal,* 7(3), 232–239.

Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM project-based learning effectiveness in Indonesia. *International Journal of Science Education*, 42(10), 1651–1672.

Wiek, A., Withycombe, L., & Redman, C. L. (2016). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6(2), 203–218.