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Science, Technology, Engineering, and Mathematics (STEM) Project-based Learning to Enhance Students' Multiliteracy on Renewable Energy: A Comparative Study between Urban and Rural Schools

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Abstract: Early renewable energy education has become increasingly vital since the urgency of sustainability in the energy sector continues to grow. This study provided a comparative analysis of students' multiliteracy enhancement between urban and rural schools in the Science, Technology, Engineering, and Mathematics Project-Based Learning (STEM-PjBL) setting. A quasi-experimental design was employed involving 120 students from one urban and one rural secondary school, selected using stratified random sampling. Multiliteracy was measured using pre- and post-tests and analyzed through normalized gain (N-gain) scores. Results indicated that both schools demonstrated moderate improvement in multiliteracy after the intervention. However, the urban school achieved relatively stronger performance compared with the rural school. It is found that urban students were associated with greater access to digital teaching and learning facilities. Conversely, rural students benefited from rich local knowledge and community practices related to natural resource management, which supported contextual understanding of renewable energy concepts. Future research is recommended to integrate sustainability education at earlier educational stages and further embed renewable energy applications within the formal curriculum to promote sustained multiliteracy development.

Keywords: Renewable energy education; Rural; STEM-PjBL; Urban

Introduction

Sustainability in the energy sector increases as the disparity between global energy demand and energy supply grows. In response to the need for sustained economic development, many nations have shifted their focus toward renewable energy sources, recognizing that the extensive use of non-renewable energy contributes significantly to environmental degradation (Sharma et al., 2021). Education plays a vital role in achieving a sustainable future by empowering young people and communities with the knowledge, skills, and moral responsibility needed to raise awareness, shape attitudes, and make informed decisions that protect the environment while promoting social and economic development (Ocetkiewicz et al., 2017). Early exposure to environmental education lays a critical foundation for developing lifelong environmental awareness, responsibility, and pro-environmental behavior (Ramulumo & Shabalala, 2024; Sadhu et al., 2018). Furthermore, incorporating renewable energy resources into educational settings as learning materials helps students develop a deeper scientific understanding while equipping them with the skills to address real-world problems (Zuvur et al., 2020).

STEM-PjBL is widely recognized as a collaborative learning approach that emphasizes real-world

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environmental challenges and is closely associated with empowering students to become environmentally conscious individuals (Al Hamad et al., 2024; Ramulumo & Shabalala, 2024). A key strength of STEM-PjBL lies in its capacity to actively engage students in solving authentic problems, both individually and collaboratively. Through structured projects, learners explore multiple strategies, test solutions, and apply disciplinary content to real-world challenges. This process encourages critical thinking, creativity, and teamwork while fostering deeper conceptual understanding (Han et al., 2016; Alkautsar et al., 2023; Indranuddin et al., 2024; Mahyudin & Herlintama, 2023; Pangestu et al., 2017).

However, despite the effectiveness of STEM-PjBL in shaping a sustainable future by equipping students with scientific knowledge and essential skills, learning facilities remain unevenly distributed across different learning settings. Disparities between rural and urban schools continue to pose persistent challenges in many countries, including Indonesia. Urban schools generally benefit from greater access to qualified teachers, adequate learning infrastructure, and up-to-date digital resources. In contrast, rural schools often struggle with limited infrastructure, higher student–teacher ratios, and restricted access to innovative and technology-based learning materials (Welsh, 2024).

A previous study by Septiyanto et al. (2024) Highlighted that STEM education equips students with the skills to innovate and develop more efficient and cost-effective solar cell technologies, and by integrating solar cell topics into STEM curricula through hands-on projects and experiments, it enhances student interest in renewable energy and sustainability while fostering environmental responsibility and inspiring future researchers and engineers (Amoah & Addoah, 2021). Komariah et al. (2022) indicate that urban students tend to perform better because they are exposed to updated curricula, engage more frequently in research- and activity-based learning, and benefit from superior infrastructure and more supportive learning environments compared to their rural counterparts. Furthermore, Syamsudin et al. (2025) highlighted that STEAM learning is found to be adaptable and impactful in improving students' scientific literacy in rural and urban school settings.

In the context of this study, the disparities between rural and urban schools are important to investigate. By comparing rural and urban schools, this research investigates how schools' geographical context influences students' opportunity to enhance multiliteracy on renewable energy that supports SDGs related to clean energy through a STEM-PjBL setting. The significance of this study stems from its ability to contribute to more inclusive and context-sensitive educational strategies that promote multiliteracy development across a variety of school contexts. However, the efficacy of educational strategies such as STEM learning varies substantially depending on the local context, especially between urban and rural schools (Muttaqiin, 2023). This study provides essential insights for curriculum creation, teacher training, and policy implementation by studying how these various contexts influence students' acquisition of multiliteracy in renewable energy. The findings are intended to encourage the development of equitable educational policies that enable all students, regardless of location, to contribute constructively to the aims of sustainable development (Ekene & Oluoch-Suleh, 2015).

This study evaluates the efficacy of STEM project-based learning in enhancing students' multiliteracy on renewable energy in both urban and rural educational settings. It specifically explores how STEM learning strategies affect students' abilities to acquire, interpret, and integrate renewable energy knowledge through multiliteracy, including STEM literacy, environmental literacy, and sustainability literacy (McBeth & Volk, 2010; Ramadhana et al., 2022). The purpose is to determine if geographical and contextual variables influence STEM learning results in developing multiliteracy, influencing future educational endeavors customized to varied school contexts (Maulana, 2020).

Method

This study employed a quasi-experimental design with a pre-test and post-test. The stratified random sampling technique was used to ensure the representation of both rural and urban school contexts. The population consisted of public secondary schools in Bandung Raya, Indonesia, which includes both rural and urban school areas that meet the basis for stratification in the sampling process. The rural and urban areas were categorized into two strata based on the geographical context, and one school from each strata was randomly selected as participants. The chosen schools each had two classes: one as the experimental group, which got the STEM-based multiliteracy intervention, and the other as the control group, which remained with the traditional curriculum. This method enabled an egalitarian representation of both contexts while retaining the aspect of random selection within each group. It improves group comparability and facilitates research on multiliteracy enhancement across a variety of school settings.

The participants of this research include 120 students from one urban school and one rural school (

Table 1). Both schools implement the Kurikulum Merdeka provided by the Indonesian Ministry of

Education. However, due to differences in curriculum implementation between the two contexts, participants were selected from various grade levels. Students in the eighth grade were specifically chosen from the rural school since the topic of renewable energy was covered at that level, according to the school curriculum. Whereas the urban school incorporates renewable energy topics within the ninth-grade science curriculum, necessitating the selection of students from that grade. This grade level distinction reflects structural variations in curricular sequencing, not disparities in student capability or developmental stage. The selection was done to ensure that all participants had the appropriate prior knowledge before or during the intervention, preserving the integrity and fairness of the learning implementation across both educational settings.

Table 1. Urban and Rural School Participants

School Location	Group	Participants (n)
Rural	Experimental	25
Rural	Control	12
Urban	Experimental	52
Urban	Control	31

The instruments were a set of 28-question multiliteracy tests that included various question types, including multiple-choice, true-or-false, short essay, and Likert-Scale questionnaire. The STEM literacy and knowledge domain on environmental literacy was in the form of an objective test that was constructed by the researcher based on curriculum content (Masturoh & Ridlo, 2020). The instrument was pilot-tested and statistically analyzed using Rasch Model Analysis to examine its validity and reliability. Expert judgment was also used to ensure the content's validity and linguistic readability. Meanwhile, to assess students' sustainability literacy, environmental behavior, and knowledge domain, the Likert-scale questionnaire was used.

The data analysis was performed using Winsteps Rasch software and SPSS. The pre-test and post-test were conducted within a 60-minute timeframe. The students' answers were evaluated and scored according to the scoring rubric. The scores of each item were subsequently entered into Winsteps Rasch to analyze the logit. The normalized Gain (N-Gain) value was calculated to evaluate the extent of learning improvement. SPSS was used to investigate the descriptive statistics analyses, including means, normality, and homogeneity. Comparative analyses of means were done to examine the difference between urban and rural school data. Data satisfying the assumptions of normality and homogeneity were analyzed using independent samples t-tests, whereas data that did not meet these assumptions were analyzed using the Mann-Whitney U test.

Result and Discussion

Given the contextual differences in access to learning resources, digital infrastructure, and prior exposure to sustainability issues, it is essential to examine how students from rural and urban settings responded to the learning intervention. Comparing these two groups allows for the identification of whether the STEM-PjBL was equally effective in supporting multiliteracy development across diverse educational contexts or whether contextual factors influenced the outcomes.

Table 2 present the gain scores and statistical analyses of multiliteracy indicators based on school location.

Table 2. Summary Statistics

Test	Type	Rural	Urban
Normality	Pretest	0.023 Not Normal	0.014 Not normal
	Posttest	0.345 Normal	0.000 Not Normal
Homogeneity	Pretest		0.005 Not Homogeneous
	Posttest		0.527 Homogeneous
Hypothesis	Wilcoxon		0.000
	Mann-Whitney		0.001

Before conducting inferential statistical analyses, assumption testing was performed to determine the most appropriate methods for comparing multiliteracy scores. The Shapiro–Wilk normality test indicated that most pretest and posttest data were not normally distributed, a pattern consistently observed across rural and urban groups and within each literacy domain. Furthermore, Levene's test for homogeneity of variance showed that while pretest scores were homogeneous between school locations, posttest scores were not. This finding suggests that although both groups began from a relatively comparable baseline, their learning outcomes diverged after the module implementation, likely due to contextual differences such as access to learning resources, technological infrastructure, and prior exposure to project-based learning.

Given the non-normal distribution and the violation of homogeneity in posttest scores, non-parametric statistical procedures were applied. The Wilcoxon signed-rank test was used to examine differences between pretest and posttest logit scores within each group, and the results demonstrated statistically significant improvements for both rural and urban students, supporting the acceptance of the alternative hypothesis (Ha). These findings confirm that the STEM–ESD-based module effectively enhanced students' multiliteracy in both contexts. To compare the magnitude of improvement between groups, a Mann–Whitney U test was conducted, yielding a statistically significant result (p = 0.001). This indicates that the level of multiliteracy improvement differed between rural and urban students, suggesting that school location meaningfully influenced learning outcomes.

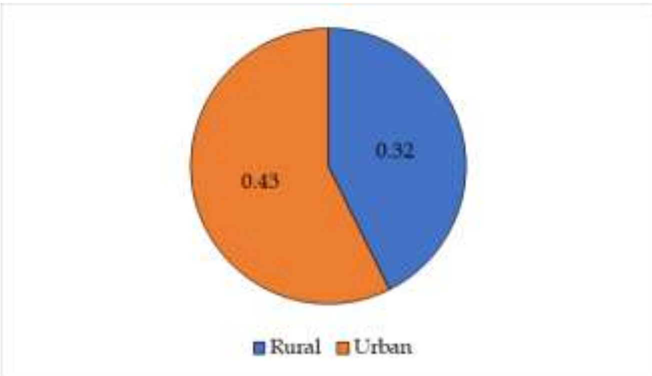

Figure 1. N-Gain

Further analysis of the N-gain scores was conducted to determine the level of enhancement in both schools. The results indicate that both groups demonstrated moderate improvement, as reflected in their normalized gain values (Figure 1). Urban students achieved an average N-gain of 0.430, while rural students obtained an N-gain of 0.320. These findings suggest that although the module was beneficial in both contexts, it had a stronger impact on urban students, possibly due to better access to learning infrastructure, greater familiarity with digital tools, and higher initial multiliteracy readiness. Nevertheless, the moderate improvement observed among rural students highlights the flexibility and inclusiveness of the module in supporting literacy development even in less advantaged settings. Overall, this result underscores the importance of context-sensitive implementation strategies and provides valuable insight for scaling and adapting STEM-PjBL across diverse educational environments.

The enhancement of multiliteracy on renewable energy in both rural and urban schools demonstrates encouraging progress, although overall achievement remains at a moderate level, with urban schools showing relatively higher proficiency. Differences in student outcomes are influenced by school location, as practical activity-based learning in rural schools often receives limited attention due to inadequate facilities and insufficient teacher expertise in conducting hands-on activities. As a result, teachers in rural schools tend to rely more heavily on classroom-based instruction, with minimal integration of practical or experimental learning experiences (Astalini et al., 2023; Borchardt et al., 2019). Urban schools typically benefit from greater access to updated technology, multimedia resources, and supportive infrastructure, which facilitate the exploration of complex renewable energy concepts through interactive and multimodal learning environments. This resource-rich context allows urban students to engage more extensively with diverse texts, simulations, and digital media related to solar, wind, and other renewable technologies, thereby fostering deeper multiliteracy development (O'Neil et al., 2020).

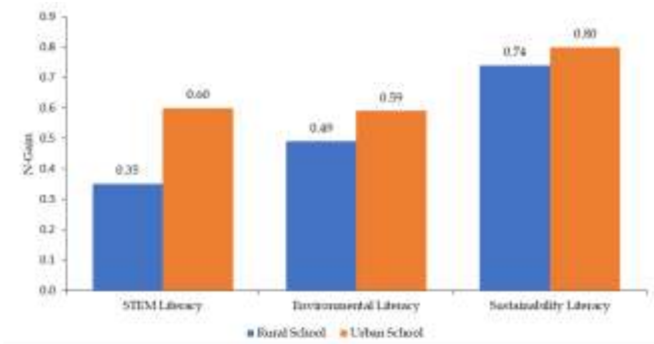

Figure 2. Multiliteracy domains enhancement

Figure 2 illustrates the normalized gain (N-gain) scores of multiliteracy domains across rural and urban schools. In all three domains, urban students demonstrate higher gains than rural students. The most pronounced difference appears in STEM literacy, where urban students show a substantially greater improvement compared to their rural counterparts. A similar pattern is observed in environmental literacy, although the gap is relatively smaller (Kaya & Elster, 2018). In sustainability literacy, both groups achieve the highest gains among the three domains, with urban students again outperforming rural students. Overall, while both schools exhibit moderate enhancement across all literacy areas, the consistently higher N-gain scores in the urban school suggest that contextual factors such as access to digital resources, infrastructure, and instructional support may contribute to stronger multiliteracy development.

In rural schools, multiliteracy enhancement related to renewable energy presents distinct challenges alongside unique contextual strengths. Limited access to stable internet connections and digital devices reduces opportunities for students to interact with rich multimedia and multimodal resources, potentially constraining the scope of literacy development (Morris et al., 2021). However, rural learning environments often draw upon local knowledge and community practices related to natural resource use, which can be meaningfully integrated into renewable energy instruction through situated multiliteracy approaches. When learning activities are connected to students' lived experiences, such as local wind conditions, sunlight intensity, or community energy practices, the relevance of multiliteracy tasks increases, enabling students to critically analyze and communicate renewable energy issues within authentic contexts. These culturally responsive strategies help sustain moderate multiliteracy gains despite existing technological limitations. The use of technology in integrated STEM learning environments enhances teaching and learning by enabling experiences that extend beyond the limitations of traditional instructional approaches (Yang & Baldwin, 2020; Siew & Ambo, 2018). The availability and effective use of digital literacy tools play a crucial role in shaping multiliteracy performance in renewable energy education across rural and urban schools.

Urban students typically benefit from greater access to simulation software, virtual laboratories, multimedia presentations, and interactive e-modules that support deeper conceptual understanding of renewable energy systems. These digital resources strengthen students' abilities to interpret data, visualize energy transformations, and produce multimodal representations that integrate text, visuals, and quantitative information. In contrast, limited digital infrastructure in rural schools often requires teachers to adopt creative, hybrid instructional approaches that combine low-tech multimodal materials, oral explanations, diagrams, and hands-on experiments (Thelma et al., 2024). Although this may restrict exposure to advanced digital literacies, it can simultaneously cultivate strong verbal, visual, and contextual multiliteracy practices grounded in community knowledge.

Cultural and linguistic diversity also influences how students access, interpret, and communicate renewable energy concepts. Urban schools, which frequently serve multilingual and culturally diverse populations, tend to foster critical literacy and intercultural communication skills as students engage with renewable energy materials from multiple perspectives. This diversity supports higher-order multiliteracy practices, such as critical framing and transformed practice, where learners evaluate assumptions, biases, and socio-political implications of energy policies. Rural students, often situated within more linguistically homogeneous communities, benefit when instruction incorporates local languages and traditional ecological knowledge, anchoring renewable energy concepts in familiar semiotic and cultural contexts (Koyama & Watanabe, 2023). Such contextualization enables meaningful engagement and supports multiliteracy development within relevant socio-environmental frameworks (Hollweg et al., 2011; Cole, 2019).

Teacher expertise and access to professional development further shape multiliteracy enhancement. Urban teachers generally have greater opportunities for training in integrating multimodal and multiliteracy-based pedagogies within renewable energy instruction. Through strategic scaffolding, these educators guide students in understanding scientific metalanguage, interpreting cross-modal representations, and critically engaging with complex data and texts (Muhaimin et al., 2020; Kennedy & Odell, 2014; Hira & Anderson, 2021). Rural teachers may face constraints in professional development access; however, targeted, context-sensitive training that emphasizes culturally relevant examples and adaptable multimodal strategies can yield promising results. Strengthening teacher capacity in both settings remains essential for sustaining multiliteracy growth.

Overall, both rural and urban schools demonstrate moderate levels of multiliteracy achievement in renewable energy education, with urban students generally performing at higher levels due to resource availability, cultural diversity, and teacher preparation. Bridging this gap requires equitable distribution of digital and multimodal resources, culturally responsive pedagogy, and sustained teacher professional development (Bahri et al., 2022; Morris et al., 2021; Welsh, 2024). By combining the technological strengths of urban schools with the contextual richness and local knowledge of rural communities, educational systems can develop complementary strategies that empower all learners to critically understand, communicate, and innovate in renewable energy for a sustainable future.

Conclusion

This study concludes that the implementation of STEM-PjBL effectively enhanced students' multiliteracy on renewable energy in both rural and urban secondary schools within the moderate category. The quasi-experimental findings involving 120 students indicate that while both groups experienced statistically significant gains, urban students achieved a higher normalized gain (0.43) compared to rural students (0.32), highlighting the influence of contextual factors such as access to digital infrastructure, learning resources, and teacher support. Nevertheless, rural students demonstrated meaningful progress, supported by the integration of local knowledge and community practices related to natural resource use, which enriched contextual understanding of renewable energy concepts.

These results underscore that STEM-PjBL is a flexible and context-responsive approach capable of fostering multiliteracy across diverse educational settings, yet its impact is shaped by structural disparities. Therefore, equitable access to digital and multimodal resources, culturally responsive pedagogy, and strengthened teacher professional development are essential to optimize multiliteracy outcomes and support sustainable energy education in varied school contexts.

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Conflicts of Interest
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References

Al Hamad, N. M., Adewusi, O. E., Unachukwu, C. C., Osawaru, B., & Chisom, O. N. (2024). A Review on the Innovative Approaches to STEM Education. *International Journal of Science and Research Archive*, *11*(1), 244–252. https://doi.org/10.30574/ijsra.2024.11.1.0026

Alkautsar, S., Nuryady, M. M., Husamah, H., Wahyono, P., & Miharja, F. J. (2023). STEM-PjBL Worksheet: Ways to Improve Students' Collaboration, Creativity, and Computational Thinking. *Jurnal Kependidikan: Jurnal Hasil Penelitian dan Kajian Kepustakaan di Bidang Pendidikan, Pengajaran dan Pembelajaran,* *9*(2), 681–695. https://doi.org/10.33394/jk.v9i2.7587

Amoah, A., & Addoah, T. (2021). Does Environmental Knowledge Drive Pro-Environmental Behaviour in Developing Countries? Evidence from Households in Ghana. *Environment, Development and Sustainability,* *23*(2), 2719–2738. https://doi.org/10.1007/s10668-020-00698-x

Astalini, Darmaji, Kurniawan, D. A., Wirayuda, R. P., Putri, W. A., Rini, E. F. S., Ginting, A. A. B., & Ratnawati, T. (2023). Impact of Science Process Skills on Thinking Skills in Rural and Urban Schools. *International Journal of Instruction*, *16*(2), 803–822. https://doi.org/10.29333/iji.2023.16242a

Bahri, A., Bin Jamaluddin, A., & Novia Arifin, A. (2022). Students' and Teachers' Digital Literacy Skill: A Comparative Study between Schools, Classes, and Genders in Urban and Rural Areas. *International Journal of Science and Research (IJSR)*, *11*(2), 184–191. https://doi.org/10.21275/SR22130101519

Berry, G., Beckman, I., & Cho, H. (2023). A Comprehensive Review of Particle Loading Models of Fibrous Air Filters. *Journal of Aerosol Science,* *167*(April), 106078. https://doi.org/10.1016/j.jaerosci .2022.106078

Borchardt, R., Salcedo, T., & Bentley, M. (2019). Little Intervention, Big Results: Intentional Integration of Information Literacy into an Introductory-Level Biology Lab Course. *Journal of Biological Education,* *53*(4), 450–462. https://doi.org/10.1080/00219266.2018.1494029

Cole, L. B. (2019). Green Building Literacy: A Framework for Advancing Green Building Education. *International Journal of STEM Education,* *6*(1). https://doi.org/10.1186/s40594-019-0171-6

Deckanio, A., Pratiwi, A. M., Ililiyun, D., Nuriyah, S., & Cahyani, T. D. (2023). Analisis Dampak Pencemaran Limbah Industri PT. S Terhadap Kehidupan Masyarakat di Kabupaten Sidoarjo. *Jurnal Ilmiah Multidisiplin,* *1*(4), 141–151. Retrieved from https://jurnal.penerbitdaarulhuda.my.id/index.php/MAJIM/article /download/97/105

Ekene, O. G., & Oluoch-Suleh, E. (2015). Role of Institutions of Higher Learning in Enhancing Sustainable Development in Kenya. *Journal of Education and Practice,* *6*(16), 91–103. Retrieved from https://eric.ed.gov/?id =EJ1079963

Han, S., Capraro, R. M., & Capraro, M. M. (2016). How Science, Technology, Engineering, and Mathematics Project Based Learning Affects High-Need Students in the U.S. *Learning and Individual Differences*, *51*, 157–166. https://doi.org/10.1016/j.lindif.2016.08.045

Hira, A., & Anderson, E. (2021). Motivating Online Learning Through Project-Based Learning During the 2020 COVID-19 Pandemic. *IAFOR Journal of Education,* *9*(2), 93–110. https://doi.org/10.22492/ije.9.2.06

Hollweg, K., Taylor, J., Bybee, R., Marcinkowski, T., McBeth, W., & Zoido, P. (2011). Developing a Framework for Assessing Environmental Literacy. North American Association for Environmental Education (NAAEE). Retrieved from https://naaee.org/sites/default/files/inline-files/devframewkassessenvlitonlin eed.pdf%0A

Indranuddin, R. D., Susetyarini, E., & Miharja, F. J. (2024). Developing STEM-PjBL Worksheet to Lift Students' Critical, Creative, and Computational Thinking Skill. *Research and Development in Education (RaDEn),* *4*(1), 85–101. https://doi.org/10.22219/raden.v4i1.27165

Kaya, V. H., & Elster, D. (2018). German Students' Environmental Literacy in Science Education Based on PISA Data. *Science Education International, 29*(2), 75–87. https://doi.org/10.33828/sei.v29.i2.2

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging Students in STEM Education. *Science Education International, 25*(3), 246–258. Retrieved from https://eric.ed.gov/?id=EJ1044508

Komariah, A., Rykova, I., Shestakov, D., Hasan, M., Achmad Kurniady, D., Grebennikova, V., Shcherbatykh, L., Kosov, M., & Dudnik, O. (2022). Assessing the quality and efficiency of education in rural schools through the models of integration and the cooperation of educational institutions: A case study of Russia and Indonesia. *Sustainability, 14*(14), 8442. https://doi.org/10.3390/su

Koyama, D., & Watanabe, T. (2023). Why a Dispositional View of Ecological Literacy is Needed. *Teaching in Higher Education, 28*(5), 1108–1117. https://doi.org/10.1080/13562517.2023.2198637

Mahyudin, R. P., & Herlintama, S. A. (2023). Estimation of Greenhouse Gas Emissions in Waste Management at Basirih Landfill Banjarmasin South Kalimantan Indonesia. *International Journal of Research and Review, 10*(6), 629–636. https://doi.org/10.52403/ijrr.20230677

Masturoh, M., & Ridlo, S. (2020). Character Building of Environmental Care on Students in Sekolah Indonesia Kota Kinabalu (SIKK) Malaysia. *Journal of Biology Education, 9*(2), 193–201. https://doi.org/10.15294/jbe.v9i2.39522

Maulana, M. (2020). Penerapan Model Project Based Learning Berbasis STEM pada Pembelajaran Fisika Siapkan Kemandirian Belajar Peserta Didik. *Jurnal Teknodik,* 39–50. https://doi.org/10.32550/teknodik.v0i2.678

McBeth, W., & Volk, T. L. (2010). The National Environmental Literacy Project: A Baseline Study of Middle Grade Students in the United States. *Journal of Environmental Education, 41*(1), 55–67. https://doi.org/10.1080/00958960903210031

Morris, J., Slater, E., Fitzgerald, M. T., Lummis, G. W., & van Etten, E. (2021). Using Local Rural Knowledge to Enhance STEM Learning for Gifted and Talented Students in Australia. *Research in Science Education, 51*, 61–79. https://doi.org/10.1007/s11165-019-9823-2

Muhaimin, Asrial, Habibi, A., Mukminin, A., & Hadisaputra, P. (2020). Science Teachers' Integration of Digital Resources in Education: A Survey in Rural Areas of One Indonesian Province. *Heliyon*, *6*(8). https://doi.org/10.1016/j.heliyon.2020.e04631

Muttaqiin, A. (2023). Pendekatan STEM (Science, Technology, Engineering, Mathematics) pada Pembelajaran IPA untuk Melatih Keterampilan Abad 21. *Jurnal Pendidikan MIPA, 13*(1), 34–45. https://doi.org/10.37630/jpm.v13i1.819

Ocetkiewicz, I., Tomaszewska, B., & Mróz, A. (2017). Renewable Energy in Education for Sustainable Development. The Polish Experience. In *Renewable and Sustainable Energy Reviews* (Vol. 80, pp. 92–97). Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.05.144

O'Neil, J. M., Newton, R. J., Bone, E. K., Birney, L. B., Green, A. E., Merrick, B., Goodwin-Segal, T., Moore, G., & Fraioli, A. (2020). Using Urban Harbors for Experiential, Environmental Literacy: Case Studies of New York and Chesapeake Bay. In *Regional Studies in Marine Science* (Vol. 33). Elsevier B.V. https://doi.org/10.1016/j.rsma.2019.100886

Pangestu, R., Riani, E., & Effendi, H. (2017). Estimasi Beban Pencemaran Point Source dan Limbah Domestik di Sungai Kalibaru Timur Provinsi DKI Jakarta, Indonesia. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan, 7*(3), 219–226. https://doi.org/10.29244/jpsl.7.3.219-226

Ramadhana, S. D., Norra, B. I., & Rasyida, N. (2022). Keefektifan Perangkat Pembelajaran Daring dengan Model PjBL-STEAM pada Materi Lingkungan untuk Meningkatkan Literasi Lingkungan. *Jurnal Pendidikan (Teori dan Praktik), 6*(2), 75–81. https://doi.org/10.26740/jp.v6n1.p75-81

Ramulumo, M., & Shabalala, N. P. (2024). Comparing Environmental Literacy in Stem and Non-Stem Preschools: Evaluating the Impact on Young Children's Understanding and Attitudes. *International Journal of Early Childhood*. https://doi.org/10.1007/s13158-024-00405-1

Sadhu, S. D., Garg, M., & Kumar, A. (2018). Major Environmental Issues and New Materials. In *New Polymer Nanocomposites for Environmental Remediation* (pp. 77–97). Elsevier. https://doi.org/10.1016/B978-0-12-811033-1.00004-4

Septiyanto, A., & Prima, E. C. (2024). STEM Education in Solar Cells: An Overview. *KnE Social Sciences*. https://doi.org/10.18502/kss.v9i13.16073

Sharma, R., Sinha, A., & Kautish, P. (2021). Does Renewable Energy Consumption Reduce Ecological Footprint? Evidence from Eight Developing Countries of Asia. *Journal of Cleaner Production*, *285*. https://doi.org/10.1016/j.jclepro.2020.124867

Siew, N. M., & Ambo, N. (2018). Development and Evaluation of an Integrated Project-Based and STEM Teaching and Learning Module on Enhancing Scientific Creativity Among Fifth Graders. *Journal of Baltic Science Education, 17*(6), 1017–1033. https://doi.org/10.33225/jbse/18.17.1017

Suciani, T., Lasmanawati, E., & Rahmawati, Y. (2018). Pemahaman Model Pembelajaran sebagai Kesiapan Praktik Pengalaman Lapangan (PPL) Mahasiswa Program Studi Pendidikan Tata Boga. *Media Pendidikan, Gizi, Dan Kuliner, 7*(1), 76–81. https://doi.org/10.17509/boga.v7i1.11599

Syamsudin, F. I., Saputro, S., Sarwanto, Karyanto, P., Yamtinah, S., Masykuri, M., & Kamari, A. (2025). Enhancing Scientific Literacy in Rural and Urban Schools Through PDP-BL with STEAM. *The Journal of Educational Research*, 1–8. https://doi.org/10.1080/00220671.2025.2590505

Thelma, C. C., Patrick, M., Sylvester, C., Mulenga, D. M., Gilbert, M. M., & Phiri, E. V. (2024). The Impact of Educational Leadership on Student Achievement: A Comparative Analysis of Urban and Rural Schools. *Asian Journal of Education and Social Studies*, *50*(8), 444–461. https://doi.org/10.9734/ajess/2024/v50i81542

Welsh, R. O. (2024). Does Rural Mean not Urban? Reconsidering the Conceptualization and Operationalization of Rural School Districts. *Urban Education*. https://doi.org/10.1177/00420859241227929

Yang, D., & Baldwin, S. J. (2020). Using Technology to Support Student Learning in an Integrated STEM Learning Environment. *The International Journal of Technology in Education and Science (IJTES) International Journal of Technology in Education and Science*, *4*(1), 1–11. https://doi.org/10.46328/ijtes.v4i1.22

Zuvur, T., Oltinboevich, J. H., Norovich, T. Y., & Sobir, K. (2020). Using alternative energy sources devices as a teaching tools. *European Journal of Research and Reflection in Educational Sciences, 8*(5). Retrieved from https://shorturl.at/jJ32g