JPPIPA 12 (7) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Integrating Local Ecological Knowledge into Elementary Science Learning for Sustainable Development: Enhancing Frog Metamorphosis Understanding and Environmental Literacy in Urban Areas

Dina Selviana[1], Wati Sukmawati[1*]

[1] Elementary School Teacher Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Prof. Dr Hamka, Jakarta, Indonesia.

Received: April 30, 2026
Revised: June 14, 2026
Accepted: July 25, 2026
Published: July 31, 2026

Corresponding Author:
Wati Sukmawati
wati_sukmawati@uhamka.com

DOI: 10.29303/jppipa.v12i7.15901

Abstract: This study aims to analyze the influence of the integration of Local Ecological Knowledge (LEK) in science learning on the understanding of the concept of frog metamorphosis and environmental literacy of elementary school students in urban areas. This study uses a quantitative approach with a pre-experimental design of a one-group pretest-posttest involving 30 elementary school students. Data were collected through concept comprehension tests and environmental literacy questionnaires, then analyzed using the N-Gain and ANCOVA tests. The results showed that the average score of concept understanding increased from 56.20 in the pretest to 82.10 in the posttest (N-Gain = 0.59), while the environmental literacy score increased from 60.35 to 85.40 (N-Gain = 0.63). The results of the ANCOVA test showed that the integration of LEK had a significant effect on concept understanding ($F = 18.42$; $p < 0.001$; $\eta^2 = 0.39$) and environmental literacy ($F = 21.17$; $p < 0.001$; $\eta^2 = 0.42$). These findings show that LEK-based learning is able to improve conceptual understanding and environmental literacy through the association of science materials with the local environmental context. Thus, the integration of LEK is an effective approach to support contextual and sustainable science learning in primary schools.

Keywords: Elementary school students; Environmental literacy; Frog metamorphosis; Local ecological knowledge (LEK); Urban

Introduction

21st century science education is no longer just oriented towards the mastery of scientific concepts, but also on the development of competencies that enable learners to understand and respond to various environmental challenges in a critical and responsible manner. Global challenges such as habitat degradation, biodiversity loss, water pollution, and climate change demand the presence of education that is able to build ecological awareness from an early age (Hernawan et al., 2022; Zidny et al., 2020). In this context, environmental literacy is one of the important competencies that need to be developed through science learning because it allows students to understand the relationship between humans, organisms, and the environment within the framework of sustainable development (Hamid et al., 2026; Michalik-Śnieżek et al., 2025). Therefore, science learning in elementary school needs to be designed not only to build conceptual understanding, but also to foster concern and responsibility for the surrounding environment (Purba et al., 2026).

However, the practice of science learning in primary schools is still often dominated by textbook-centric approaches and abstract presentation of concepts. Learning that does not connect the material with the real-life context causes students to have

How to Cite:
Selviana, D., & Sukmawati, W. (2026). Integrating Local Ecological Knowledge into Elementary Science Learning for Sustainable Development: Enhancing Frog Metamorphosis Understanding and Environmental Literacy in Urban Areas. *Jurnal Penelitian Pendidikan IPA*, *12*(7), 172–180. https://doi.org/10.29303/jppipa.v12i7.15901

difficulty understanding the relationship between scientific concepts and the phenomena they encounter on a daily basis. As a result, science learning tends to result in mastery of memorized concepts without being followed by the ability to apply this knowledge in dealing with environmental problems (Pratama et al., 2026; Purwasih et al., 2025). This condition has an impact on low conceptual understanding and the development of student environmental literacy is not optimal. These challenges are increasingly complex in urban areas due to the limited direct interaction of students with biodiversity and natural ecosystems that are the object of science study (Aurélio et al., 2021; Li & Shein, 2023).

One of the science materials that has great potential to connect science concepts with environmental issues is the metamorphosis of frogs. Frogs are amphibious organisms that undergo a gradual transformation of form from eggs, tadpoles, young frogs, to adult frogs. The success of the life cycle is greatly influenced by the quality of the aquatic environment and the availability of suitable habitat. Due to their sensitivity to changing environmental conditions, frogs are often used as a biological indicator of ecosystem health. Thus, studying frog metamorphosis not only serves to introduce the concept of the development of living things, but can also be a means to understand the relationship between biodiversity, environmental quality, and ecosystem sustainability. Learning that links the metamorphosis of frogs to the conditions of the surrounding environment has the potential to help students build a deeper understanding of the concept while increasing their ecological awareness (Cronin et al., 2025; Murung, 2025).

To realize contextual and meaningful learning, an approach is needed that is able to bridge scientific concepts with students' real experiences. One of the approaches that is getting more and more attention in science education is integration Local Ecological Knowledge (LEK) or local ecological knowledge (Brannelly et al., 2025; Irie & Iwai, 2025). LEK includes knowledge, experience, values, and practices of the community in interacting with the environment formed through social and cultural processes over a long period of time. In the perspective of ethnoscience, local knowledge is not positioned as opposed to modern science, but rather as a learning resource that can be used to help learners build scientific understanding based on a context close to their lives (Duda et al., 2024; Harris et al., 2025). Various studies show that the integration of local knowledge in science learning can improve learning motivation, concept understanding, critical thinking skills, and concern for the environment.

However, according to most research on ethnoscience and local ecological knowledge, it still focuses on indigenous peoples or rural areas that have strong ecological traditions (Aurélio et al., 2021; Cronin et al., 2025; Li & Shein, 2023). Studies exploring the use of local ecological knowledge in urban contexts are still limited, especially at the primary school level. In fact, urban areas also have a distinctive form of ecological knowledge that develops through community interaction with rivers, reservoirs, green open spaces, urban parks, and biodiversity that still survive amid urbanization pressures. This knowledge can be a relevant learning resource to help students understand the relationship between science concepts and the environmental issues they face firsthand.

Jakarta as one of the largest metropolitan cities in Southeast Asia faces various ecological challenges, such as water pollution, reduced natural habitats, and declining urban biodiversity. On the other hand, in accordance with various environmental conservation efforts, such as the revitalization of rivers and reservoirs, the development of green open spaces, and urban environmental preservation programs, it has given birth to the practice of local ecological knowledge that can be used as a source of contextual learning (Pratama et al., 2025). The existence of frogs in urban areas of Jakarta is an interesting phenomenon because it ecologically reflects the condition of the aquatic habitat and the quality of the local environment. Therefore, frog metamorphosis material has the potential to be integrated with the local ecological knowledge of urban communities to create a more authentic and meaningful learning experience for students.

Although previous research has reported the benefits of integrating local knowledge in science learning, there are still gaps in research related to utilization Local Ecological Knowledge in an urban context to study biology in elementary schools. In particular, there has been little research examining how the local ecological knowledge of urban communities can be integrated into frog metamorphosis learning to improve students' conceptual understanding as well as environmental literacy. In addition, studies linking science education, urban biodiversity, and environmental literacy within a single integrated learning framework are still relatively limited (Brannelly et al., 2025; Harris et al., 2025; Irie & Iwai, 2025).

Based on these gaps, this study aims to analyze the integration of local ecological knowledge in science learning on frog metamorphosis material and its influence on the conceptual understanding and environmental literacy of elementary school students in urban areas. This research is expected to make a theoretical contribution to the development of ethnoscience studies, Local Ecological Knowledge (LEK), and place-based science education in urban contexts, as well as offer contextual, relevant, and sustainable science learning models to strengthen students' environmental literacy since primary education.

Method

This study uses Quantitative with a pre-experimental design, namely One-group pretest-posttest design (Arrauyani et al., 2025; Hermanto et al., 2025; Sukmawati et al., 2026), to test the influence of integration Local Ecological Knowledge (LEK) in science learning about understanding the concept of frog metamorphosis and environmental literacy of elementary school students in urban areas.

In this design, there is only one group of trials that are given a pretest before treatment and a posttest after treatment.

Table 1. Research Design

Group	Pretest	Treatment	Post-tests
Experiment	O_1	X	O_2

Remarks: O_1 = pretest; O_2 = posttest; X = Science learning based on local ecological knowledge (LEK)

Location and Research Participants

The research was conducted in one of the public elementary schools in urban Jakarta that has the characteristics of an urban environment such as drainage channels, green open spaces, and small aquatic ecosystems that can still be observed by students.

The research participants are grade IV elementary school students who have studied animal life cycle material in the science curriculum. Samples selected using Destination sampling, with the sum of 32 students in one experimental class. Students take part in science learning about frog metamorphosis material developed based on integration Local Ecology (LEK) knowledge, ethnoscience, and place-based science education that connect scientific concepts with students' urban environments (Febianti et al., 2024; Hartomo et al., 2024; Sukmawati et al., 2025; Tsabitah et al., 2025). Learning is carried out during 4–6 meetings with stages:

a) *Exploration of local knowledge*

Identify students' initial experiences and misconceptions related to frogs and the environment.

b) *Environmental observation/local case studies*

Students make direct observations of the school environment such as drainage, standing water, and parks.

c) *Construction of scientific concepts*

The teacher directs students to build a scientific concept of frog metamorphosis based on observations.

d) *Simple conservation reflections and measures*

Students reflect on ecological relationships and take simple actions such as keeping the school environment clean.

Figure 1. Implementation of Learning based on Local Ecological Knowledge

Research Instruments

Test of Understanding the Concept of Frog Metamorphosis

Conceptual understanding was measured using 15 multiple-choice tests and 5 descriptive questions, which included material on the stages of frog metamorphosis, morphological changes in each phase, environmental factors that affect the frog's life cycle, and the relationship between metamorphosis and habitat conservation. The instrument is compiled based on elementary school science competency indicators and has been tested using expert assessments by three experts (science education lecturers, learning evaluation experts, and basic science teachers). The validity was calculated using V Aiken with a value of 0.86 and the reliability value of the instrument was tested using Alpha Cronbach, with a value of 0.75 so that the instrument was suitable for use.

Data Collection Procedure

The research was carried out through the following stages:

a) Identify the context of Local Ecological Knowledge in the school environment.
b) Development of LEK-based learning tools.
c) Implementation of pretests in experimental classes.
d) Implementation of LEK-based learning (4-6 meetings).

e) Post-test implementation

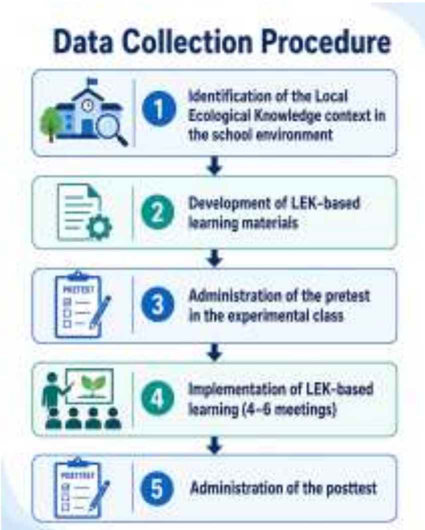

Figure 2. Research procedure

Data Analysis Techniques

Data analysis was carried out quantitatively using inferential and descriptive statistics.

a) Descriptive Statistics

Including average values, standard deviations, minimums and maximums.

b) N-Gain

Used to measure improvement before and after learning.

c) Normality Test

Use Shapiro-Wilk to test the distribution of data.

d) Homogeneity Test

Using the Levene test.

e) Effectiveness Test

Since there was only one group, learning effectiveness was analyzed using Paired Sample t-tests (pretest vs posttest) and effect measures (Cohen's d) to see the strength of the intervention's influence.

Result and Discussion

The results of the study showed a significant increase in understanding of the concept of frog metamorphosis and students' environmental literacy after the application of Local Ecological Knowledge (LEK)-based learning in urban contexts. The analysis was conducted based on pretest-posttest data from 30 students with descriptive, N-Gain, and inferential statistical approaches.

Description of the Concept of Understanding Statistics

The results of the descriptive analysis showed that the average pretest score of students' concept understanding was 56.20 (SD = 4.28), with a minimum score of 49 and a maximum of 63. After the LEK-based learning intervention, the average posttest score increased to 82.10 (SD = 3.96) with a minimum score of 77 and a maximum of 92.

Table 2. Descriptive Statistics to Understand the Concept of Frog Metamorphosis

Variable	N	Red	SD	Minutes	Max
Prates	30	56.20	4.28	49	63
Post-tests	30	82.10	3.96	77	92

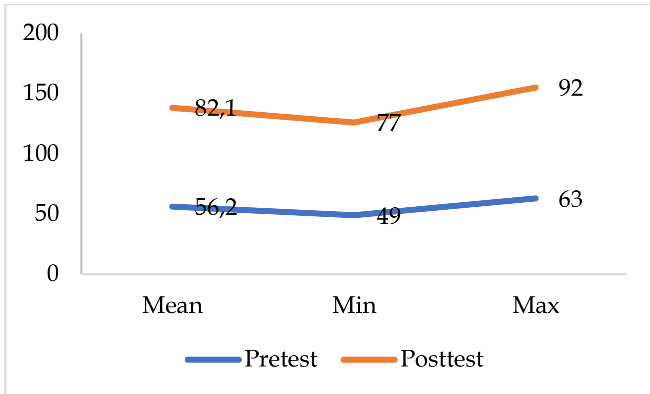

Figure 3. Average posttest performance table

There was an increase of 25.9 points, indicating a significant increase after the LEK intervention. This increase shows a significant shift in students' understanding of the concept of frog metamorphosis, from the low-medium category to the high category.

The Concept of Understanding N-Gain

The calculation of N-Gain shows an average value of 0.59, which falls into the medium-high category. The distribution of students' individual N-Gain shows that most students (above 80%) are in the medium to high category, with some students reaching the high category (≥0.70), such as S24 (0.78) and S9 (0.73).

Table 3. N-Gain Understanding Concept

Category	Value
En-gain rata-rata	0.59
Category	Medium–High

Table 4. Concept of Understanding N-Gain Distribution

Category	Number of Students	Percentage
Height (≥0.70)	6	20%
Medium (0.30–0.69)	24	80%
Low (<0.30)	0	0%

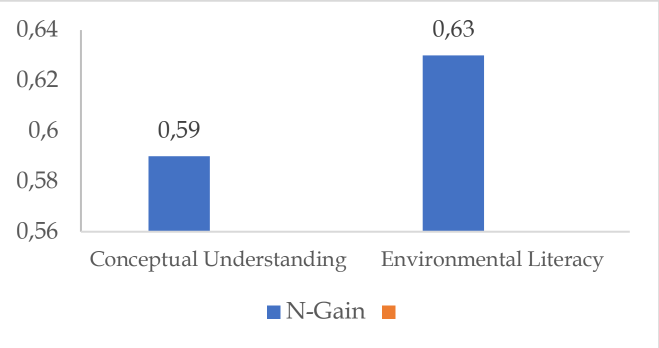

Figure 4. Normalized reinforcement table

This shows that LEK-based learning makes a significant contribution to improving students' conceptual understanding evenly.

Description of Environmental Literacy Statistics

In the environmental literacy variable, the average pretest score was 60.35 (SD = 3.92) with a minimum score of 55 and a maximum of 66. After treatment, there was an increase to 85.40 (SD = 3.88) with a minimum score of 80 and a maximum of 93.

Table 5. Environmental Literacy Statistics

Variable	N	Red	SD	Minutes	Max
Prates	30	60.35	3.92	55	66
Post-tests	30	85.40	3.88	80	93

The increase of 25.05 points shows a significant strengthening of environmental literacy. This increase shows that students not only experience an increase in knowledge, but also the development of awareness and attitude towards the environment.

N-Gain Environmental Literacy

The results of the N-Gain analysis showed an average value of 0.63, which is included in the medium-high category. Most students showed consistent improvement, with some students achieving high categories such as S24 (0.79) and S9 (0.77).

Table 6. N-Gain Environmental Literacy

Category	Value
average n-gain	0.63
Category	Medium–High

Table 7. Environmental Literacy N-Gain Distribution

Category	Number of Students	Percentage
Height (≥0.70)	7	23.3%
Medium (0.30–0.69)	23	76.7%
Low (<0.30)	0	0%

These findings show that LEK-based learning is effective in significantly improving environmental literacy.

Inferential Test (ANCOVA)

The results of the ANCOVA test showed that LEK-based learning had a significant influence on both research variables after controlling for pretest scores. For conceptual understanding, the value $F(1, 57) = 18.42$ is obtained; $p < 0.001$; $\eta^2 = 0.39$, which indicates a large effect. Meanwhile, in environmental literacy, the value of $F(1, 57) = 21.17$ was obtained; $p < 0.001$; $\eta^2 = 0.42$, which also shows a big effect. These results show that LEK interventions have a strong contribution in improving student learning outcomes both in cognitive and affective aspects.

Table 8. ANCOVA Results

Variable	F	p	h²	Interprets
Concept Understanding	18.42	<0.001	0.39	Huge effect
Environmental Literacy	21.17	<0.001	0.42	Huge effect

Discussion

The results of the study show that the increase in understanding of the concept of frog metamorphosis and students' environmental literacy cannot be separated from the learning based learning design Local Ecological Knowledge (LEK) which is carried out through four systematic stages during 4-6 meetings, namely exploration of local knowledge, environmental observation or local case studies, construction of scientific concepts, as well as environmental reflection and simple conservation actions. Each stage makes a different but complementary contribution in building students' conceptual understanding and ecological awareness. This gradual approach is in line with the principle of scaffolding learning in Vygotsky's social constructivism, in which students are progressively guided from concrete experience to abstract scientific understanding through meaningful social interaction and environmental context (Homayouni, 2022; Wibowo et al., 2025; Zhang et al., 2026).

The Exploration of Local Knowledge Stage is the starting point in uncovering misunderstandings and students' initial experiences related to frog metamorphosis. At this stage, based on the results of the pretest on a reasoned multiple-choice instrument and its brief description, it was found that most students still had the misconception that tadpoles were "fish chicks" (about 70%). Instruments that include indicators of stages of metamorphosis, morphological changes, environmental factors, and ecological relationships show that students' initial understanding is still intuitive and not yet scientific (Chen & Adams, 2023; Wibowo et al., 2025). These findings also suggest that the concept of metamorphosis is still understood separately from the environmental context, as commonly found in textbook-oriented science learning (Novianti et al., 2023; Nurliana et al., 2023; São Paulo et al., 2024).

The second stage, namely environmental observation or local case studies, Provide hands-on experience to students through observation of waterways, puddles, and green open spaces around the school. This activity serves as a Triggers of Cognitive Conflict Important in the process conceptual change the findings show that about 85% of students begin to identify the presence of organisms they find as part of the frog's life cycle after observation. For example, students who previously thought of tadpoles as fish began to realize that the organism coexisted with frogs in the same habitat. This activity also strengthens the dimensions of Environmental Knowledge and Ecological Awareness in the environmental literacy questionnaire, because students began to associate water conditions with the existence of living organisms (Ali et al., 2026; Lin et al., 2025; Tian & Chen, 2023).

The third stage, namely the construction of scientific concepts, is an important phase in connecting the results of observations with formal scientific concepts. The teacher facilitated the discussion to explain the stages of frog metamorphosis (egg-tadpole-young frog-adult frog), morphological changes, and environmental factors that affect the life cycle, such as water quality and habitat availability. Posttest results showed a significant increase from 56.20 to 82.10 (N-Gain = 0.59), which showed that students were able to reconstruct scientific concepts more accurately. This change shows that the test instruments used not only measure memorization, but also the ability to reason through reasoned questions, which reflects an improvement in Students' Scientific Reasoning (Guerrero Fernández et al., 2022; Tian & Chen, 2023).

The fourth stage, namely Environmental reflection and simple conservation measures, has the strongest impact on the affective and behavioral aspects of students. At this stage, students are asked to reflect on the relationship between environmental conditions and frog survival and design simple actions such as keeping sewers clean and not littering (Odo et al., 2026; Rodríguez Pérez et al., 2024). The results of the environmental literacy questionnaire showed an increase from 60.35 to 85.40 (N-Gain = 0.63), especially in the dimensions of attitude, ecological awareness, and pro-environmental behavior. This shows that learning does not only stop at understanding concepts, but also encourages the transformation of attitudes and real actions, in accordance with Environmental Literacy Framework (Ambarwati et al., 2026; Rahmat et al., 2026; Singh et al., 2025).

In more detail, qualitative data support quantitative findings. One of the students (S1) who at the initial stage stated that "tadpoles are small fish" showed a conceptual change after observation activities, to "tadpoles are the early stages of frogs that live in water." These changes reflect conceptual changes driven by direct experience and scientific clarification. Another student (S2) attributed the existence of tadpoles to environmental quality, stating that "dirty water makes tadpoles incapable of living," which shows the integration between biological concepts and ecological awareness The ability to connect biological phenomena with environmental conditions is one of the indicators of the development of environmental literacy and systemic thinking in science learning. Meanwhile, students (S3) showed a change in the behavioral dimension by expressing a desire to maintain the cleanliness of the school environment so that frogs can live well.

The integration of LEK in these four stages shows that local context-based learning serves as a bridge between students' empirical experiences and formal scientific concepts. In the urban context, LEK is not only in the form of traditional knowledge, but also in the form of students' daily experiences of urban environments such as drainage, flooding, and green open spaces. Therefore, LEK in this study can be understood as urban ecology knowledge, which expands the concept of LEK in the science education literature. These findings reinforce the view that urban environments have great potential as authentic learning ecosystems for science learning

Theoretically, the success of these interventions can be explained through the integration of three main frameworks, namely social constructivism, which emphasizes the role of social interaction in knowledge formation emphasizing the cycle of experience–reflection–conceptualization–action; and place-based education, which emphasizes the linkage between learning and the local environment of students. The combination of these three approaches explains why there has been a significant improvement in both students' understanding of environmental concepts and literacy.

Thus, the results of this study show that the LEK-based learning design structured through four learning stages, supported by instruments that measure cognitive (concept tests) and affective-behavioral aspects (environmental literacy questionnaires), is able to produce science learning that is more meaningful, contextual, and sustainability-oriented. These findings make an important contribution to the international science education literature, especially in expanding the application of LEK in urban contexts that are still relatively underexplored.

Conclusion

This research shows that the integration of Local Ecological Knowledge (LEK) into basic science learning effectively improves students' understanding of the concept of frog metamorphosis and environmental literacy in urban contexts. The implementation of LEK-based learning through four systematic stages—exploration of local knowledge, environmental observation, construction of scientific concepts, and reflection of the environment with simple conservation actions—provides a meaningful learning experience by connecting scientific concepts with students' daily ecological environment. These findings showed significant improvements in both variables after the intervention. Students' conceptual comprehension increased from a pretest average score of 56.20 to a posttest average score of 82.10 with an N-Gain of 0.59, while environmental literacy increased from 60.35 to 85.40 with an N-Gain of 0.63. Furthermore, the results of ANCOVA confirm that LEK-based learning produces statistically significant and large effects on both conceptual comprehension ($F = 18.42$; $p < 0.001$; $\eta^2 = 0.39$) and environmental literacy ($F = 21.17$; $p < 0.001$; $\eta^2 = 0.42$). These results suggest that contextual learning based on local ecological experiences contributes substantially to students' cognitive achievement as well as their environmental awareness and responsible attitudes. Theoretically, this study expands the application of Local Ecological Knowledge beyond rural and customary environments by demonstrating its relevance in urban ecosystems. It also strengthens the integration of ethnoscience, place-based education, and social constructivist learning theory in science education. In practical terms, the findings suggest that urban ecological resources, such as drainage systems, green open spaces, and local biodiversity, can serve as authentic learning environments for basic science education. Despite these promising findings, the study was limited by the use of a single-group pretest-posttest design and a relatively small sample from a single elementary school. Future studies are recommended to use quasi-experimental or true experimental designs involving a larger, more diverse sample in different urban areas. Further research may also investigate the long-term effects of LEK-based learning on students' environmental behavior, scientific literacy, and sustainability competencies. Overall, integrating Local Ecological Knowledge into basic science learning is an effective, contextual, and sustainable educational approach that not only enhances students' conceptual understanding but also fosters environmental literacy and ecological responsibility, supporting the development of knowledge-literate citizens who are able to address future environmental challenges. The main conclusions of this study can be presented in a brief Conclusion section, which can stand alone or form a subsection of the Discussion or Results and Discussion section.

Acknowledgments
The author would like to express his gratitude to the Faculty of Teacher Training and Education, University of Muhammadiyah Prof. DR. HAMKA (UHAMKA), who has provided academic support and a conducive research environment during this research. The author also expressed his gratitude to the principals, teachers, and fourth grade elementary school students who participated in Jakarta for their cooperation and active participation during the implementation of this research. The authors further appreciate the valuable comments and constructive suggestions provided by colleagues and reviewers, which contribute significantly to improving the quality of this manuscript.

Author Contributions
All authors contributed to writing this article.

Funding
No external funding.

Conflicts of Interest
No conflict interest.

References

Ali, A.S., Alemayehu, Y.A., & Gebreeyessus, G.D. (2026). Education for Environmental Literacy: Insights into Adolescent Behavior in Urban Ethiopia and Developing Countries. *Australian Journal of Environmental Education*. https://doi.org/10.1017/aee.2026.10176

Ambarwati, A., Prasetyo, H. D., Murniatie, I. U., Umamah, A., Laila, W. R., Mahfud, S. R., Salsabila, A. R., & Affendi, N. R. M. (2026). Literature-Based Environmental Literacy for Junior High School Students' Understanding of Local Ecology in East Java. *BIO Web Conference*, *209*. https://doi.org/10.1051/bioconf/202620904013

Arrauyani, S., & Sukmawati, W. (2025). The effect of the use of HBA (Human Body Anatomy) media on the understanding of the concept of the human body skeleton in grade VI elementary school students. *Jurnal Penelitian Pendidikan IPA, 11*(9), 926–933. https://doi.org/10.29303/jppipa.v11i9.11690

Aurélio, L., França, S., Sequeira, V., Boaventura, D., Correia, M. J., Pinto, B., Amoroso, S., Feio, M. J., Brito, C., Chainho, P., & Chaves, L. (2021). Tell to Save the River: Assessing the Impact of Using Children's Books in the Classroom as a Tool to Promote Environmental Awareness. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.699122

Brannelly, L. A., Ohmer, M. B., Zimmerman, L., Wantman, T. M., Reuben, P. L., Zegar, J., Fontaine, S. S., Bletz, M. C., LaBumbard, B. C., Venesky, M. D., Cramp, R. L., Woodhams, D. C., & Richards-

Zawacki, C. L. (2025). Post-metamorphic growth partially compensates for the effects of climate-driven stress on juvenile frog performance. *Ecology*, *16*(2). https://doi.org/10.1002/ecs2.70177

Chen, J. J, & Adams, C. B. (2023). Taking from and Expanding Their Toolbox: Preschool Teachers' Traditional Strategies, Unconventional Opportunities, and New Challenges in Scaffolding Young Children's Social and Emotional Learning During Remote Teaching Amid COVID-19. *Journal of Early Childhood Education*, *51*(5), 925–937. https://doi.org/10.1007/s10643-022-01359-6

Cronin, A. D., Smit, J. A., Ellers, J., & Halfwerk, W. (2025). The environment of urban development changes the phenotype of tadpoles depending on their origin. *Journal of Animal Ecology*, *94*(9), 1707–1719. https://doi.org/10.1111/1365-2656.70071

Duda, E., Anacka, H., Obracht-Prondzyńska, H., Geirbo, H. C., & Kowal, J. (2024). Improving environmental literacy through urban technology-based learning. Pala application case. *30th American Conference on Information Systems, AMCIS 2024*. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-85213061568&partnerID=40&md5=e6fd9081d294a39bdbe7b70ae6ce48fa

Febianti, F. A., & Sukmawati, W. (2024). Improving Students' Science Literacy Skills through Treasure Hunting Games with a Problem-Based Learning Model. *Jurnal Penelitian Pendidikan IPA, 10*(9), 6363–6375. https://doi.org/10.29303/jppipa.v10i9.7996

Guerrero Fernández, A., Rodríguez Marin, F., Solís Ramírez, E., & Rivero García, A. (2022). Teacher environmental literacy in early childhood and elementary education training. *Journal of Interuniversity Teacher Training*, *97*(36.1), 75–98. https://doi.org/10.47553/rifop.v97i36.1.92434

Hamid, S., Swandi, A., Amal, A., Ilham, M.S., & Arif, A. (2026). Exploration of Local Wisdom of the Nusantara Region to design ethno-STEM project-based learning modules for ecological awareness learning. *F1000Research*, *15*. https://doi.org/10.12688/f1000research.178677.1

Harris, N. C., González, G., & Vrla, S. (2025). Environmental characteristics of environmental literacy in urban youth: a case from the Detroit Metropolitan Area, USA. *City*, *163*. https://doi.org/10.1016/j.cities.2025.106042

Hartomo, R. M., & Sukmawati, W. (2024). The Effect of Digital Flipbook Media on Improving Science Literacy on Human Digestive System Materials Among Elementary School Students. *Jurnal Penelitian Pendidikan IPA, 10*(9), 6260–6270. https://doi.org/10.29303/jppipa.v10i9.7994

Hermanto, A. M., & Sukmawati, W. (2025). Changes in Energy Material Learning Outcomes and Their Changes through the Team Games Tournament (TGT) Cooperative Learning Model in Grade IV Elementary School Students. *Jurnal Penelitian Pendidikan IPA, 11*(9), 919–925. https://doi.org/10.29303/jppipa.v11i9.11688

Hernawan, A. H., Darmawan, D., & Ali, M. (2022). Environmental Education Based On Local Values: Its Integration Into The Indonesian Elementary School Curriculum. *International Journal of Education and Practice*, *10*(4), 322–333. https://doi.org/10.18488/61.v10i4.3174

Homayouni, M. (2022). Peer assessment in a group-oriented classroom context: on the effectiveness of peer assessment coupled with scaffolding and group work on speaking skills and vocabulary learning. *Language Testing in Asia*, *12*(1). https://doi.org/10.1186/s40468-022-00211-3

Irie, S., & Iwai, N. (2025). Examination of the existence of evolutionary responses behind larger sizes at metamorphosis in urban toads. *Urban Ecosystems*, *28*(3). https://doi.org/10.1007/s11252-025-01721-7

Li, W. T., & Shein, P. P. (2023). Developing a sense of place through place-based traditional education for the sustainable development curriculum. *Environmental Education Research*, *29*(5), 692–714. https://doi.org/10.1080/13504622.2022.2098933

Lin, S. -H., Sah, A. K., & Hong, Y. -M. (2025). Environmental literacy among the general public in Chiayi County, Taiwan. *Sustainability (Switzerland), 17*(7). https://doi.org/10.3390/su17073108

Michalik-Śnieżek, M., Trzaskowska, E., Nowak-Kępczyk, M., Kułak, A., Lipińska, H., & Wyłupek, T. (2025). Experience-Based Environmental Education as a Tool to Increase Awareness of Ecosystem Services among Adolescents: Evidence from an Outdoor Workshop in Lublin, Poland. *Sustainability (Switzerland), 17*(23). https://doi.org/10.3390/su172310439

Moody, H. (2025). Research and Applied Scientific Action in Experiential Learning: Indian River Lagoon, Florida. In *Experiential Learning in Geography: The World as Our Classroom* (pp. 91–104). https://doi.org/10.1007/978-3-031-82575-0_6

Novianti, R., Aisyah, W. N., & Sukmawati, W. (2023). Analysis of students' wrong answers to the understanding of energy concepts in text-based learning of conceptual change (CCT). *Journal of Science Education Research*, *9*(2), 505–508. https://doi.org/10.29303/jppipa.v9i2.2049

Nurliana, N., & Sukmawati, W. (2023). A systematic analysis of the application of the RADEC model to the creativity of grade IV elementary school students in water cycle materials. *Journal of Science Education Research*, *9*(8), 5964–5970. https://doi.org/10.29303/jppipa.v9i8.3951

Odo, V. O., Ike, O. O., & Isife, O. G. (2026). Perceptions of Climate Change and Environmental Anxiety among Young Adults in Sub-Saharan Africa: Does Environmental Literacy Have a Role? *Global Social Welfare*. https://doi.org/10.1007/s40609-026-00468-z

Pratama, D. F., Sopandi, W., & Riandi, R. (2026). The Development Of Tdba-Based Augmented Reality Learning E-Modules - Radec Towards Improving Students' Environmental Literacy To Support The Sustainable Development Goals (SDGS). *Journal of Engineering Science and Technology*, *21*(1), 73–80. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-105028020758&partnerID=40&md5=187cc0c338acfc3a719c12c883c1fc59

Purba, L. L., Dasna, I. W., Munzil, M., & Wonorahardjo, S. (2026). Green chemistry learning: Project-based integrated local wisdom to foster students' environmental awareness and learning motivation. *Journal of Multidisciplinary Science*, *8*(9). https://doi.org/10.31893/multiscience.2026590

Purwasih, D., Wilujeng, I., Wiyarsi, A., & Zakwandi, R. (2025). Socio-scientific issues based on local potential in integrated learning instruction to improve students' ecological literacy. *Science and Education*. https://doi.org/10.1007/s11191-025-00671-y

Rahmat, H. K., Syah, N., Barlian, E., Hafidzah, N. H., Umar, I., & Veronika, N. (2026). Environmental Literacy and Coastal Education as a Path to Marine Ecosystem Conservation: A Review of the Systematic Literature. *Journal of Aquatic and Fisheries Biology of Egypt*, *30*(2), 1933–1946. https://doi.org/10.21608/ejabf.2026.475064.7671

Rodríguez Pérez, L., Azcárate Goded, M. D. P., & García-González, E. (2024). Environmental Literacy in Early Teacher Training: Pre-service Teachers' Perceptions of the Social-Environmental Impact of Food. *Education*, *14*(8). https://doi.org/10.3390/educsci14080912

Saputri, A. L., & Sukmawati, W. (2024). The influence of the Team Games Tournament (TGT) learning model fostered by Wordwall on the scientific literacy of grade V elementary school students. *Journal of Science Education Research*, *10*(7), 3787–3798. https://doi.org/10.29303/jppipa.v10i7.7992

Singh, A., Kazi, R., Gorde, S., Shukla, R. P., Gawande, A., & Kumar, A. (2025). Exploring the Role of Environmental Education in Promoting a Sustainability Mindset: Empirical Analysis Using Advanced and Hierarchical Regression Methods. *Natural Environment and Pollution Technology*, *24*(3). https://doi.org/10.46488/NEPT.2025.v24i03.B4290

Sukmawati, W., Adlawan, H. A., & Andarawan, N. D. (2025). Analysis of science literacy and environmental awareness of elementary school students through the use of STEM-based solar sprinkle and ecoburn media in science learning. *Journal of Science Education Research*, *11*(5), 274–281. https://doi.org/10.29303/jppipa.v11i5.11470

Sukmawati, W., Maarif, S., Cianda, F., Burhendi, A., Kadir, K. A., Jamaludin, N. B., Shaari, H., & Adlawan, H. A. (2026). Teachers' Readiness and Perception of Augmented Reality for Sustainable STEM Education. *Journal of Science & Technology Innovation*, *5*(1), 53–66. https://doi.org/10.56566/amplitudo.v5i1.505

Tian, H., & Chen, S. (2023). Structural Analysis of Environmental Literacy of Urban Residents in China—Based on Qingdao Population Questionnaire Survey. *Sustainability (Switzerland), 15*(6). https://doi.org/10.3390/su15065552

Tsabitah, H. K., & Sukmawati, W. (2025). The effect of the use of MAGICO (Active Magnetics for Games and Cognitive Interaction) media on changes in the understanding of the concept of magnetism in grade IV elementary school students. *Jurnal Penelitian Pendidikan IPA, 11*(8), 629–635. https://doi.org/10.29303/jppipa.v11i8.11539

Wibowo, S., Wangid, M. N., & Firdaus, F. M. (2025). The relevance of Vygotsky's constructivist learning theory to different elementary schools of learning. *Journal of Education and Learning*, *19*(1), 431–440. https://doi.org/10.11591/edulearn.v19i1.21197

Zhang, W., Yu, H., Xia, M., Yang, M., & Ja, J. (2026). Beyond tutoring: a child-centered AI framework for construction embodied in culture-based steam education. *Education and Information Technology*. https://doi.org/10.1007/s10639-026-14030-z

Zidny, R., Sjöström, J., & Eilks, I. (2020). Multi-perspective reflection on how indigenous knowledge and related ideas can enhance science education for sustainability. *Science and Education*, *29*(1), 145–185. https://doi.org/10.1007/s11191-019-00100-x