



A Hybrid Science Learning Model Integrating Local Wisdom and Digital Technology to Enhance Scientific Literacy and Ecological Character of Elementary School Students (SDG 4)

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Abstract: This study aimed to develop and implement a hybrid biology learning model integrating local wisdom and digital technology to improve scientific literacy and strengthen the ecological character of elementary school students. A Design-Based Research (DBR) approach was employed, involving fifth-grade students as research subjects. Data were collected through observations, interviews, scientific literacy tests, ecological character questionnaires, and documentation. Quantitative data were analyzed using N-Gain and paired sample t-tests, while qualitative data were analyzed through data reduction, data display, and conclusion drawing. The results showed a significant improvement in students' scientific literacy, with average scores increasing from 55.4 to 81.7 and an N-Gain value of 0.60 (moderate category). Students' ecological character also improved from 68.35 (fair) to 86.94 (very good). Teachers' and students' responses indicated that the model was practical, engaging, and easy to implement, while expert validation confirmed its validity and feasibility. Overall, the findings indicate that the proposed hybrid learning model offers an effective and innovative approach for enhancing both cognitive and affective learning outcomes in elementary science education.

Keywords: Digital technology; Ecological character; Elementary science education; Hybrid learning model; Local wisdom; Scientific literacy

Introduction

Education at the elementary school level serves as the main foundation for developing young generations' competencies, including scientific literacy skills and character formation. Scientific literacy is one of the essential 21st-century skills, as it not only involves understanding scientific concepts but also the ability to think critically, make data-driven decisions, and apply scientific knowledge in everyday life. Unfortunately, international assessments such as the Programme for International Student Assessment (PISA) indicate that Indonesian students' scientific literacy remains at a low level (OECD, 2019). This condition highlights the urgent

need for innovative science learning at the elementary level to foster scientific literacy from an early age. Ideally, biology learning in elementary schools should provide learning experiences closely connected to students' daily lives. However, current instructional practices remain largely focused on memorization and textbook-oriented activities (Sulianto et al., 2019). Students are more often engaged in drill-based exercises than encouraged to explore their surrounding environment. As a result, they experience difficulties in connecting biological concepts with real-life phenomena, leading to less meaningful learning experiences. Previous studies have consistently reported

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that Indonesian students still struggle to apply scientific concepts in real-world contexts (Lestari et al., 2022).

Scientific literacy is one of the essential skills that should be developed from the elementary school level to prepare students to face 21st-century challenges. However, various studies indicate that the level of scientific literacy among elementary school students is still relatively low. Previous studies published in *Jurnal Penelitian Pendidikan IPA (JPPIPA)* have consistently reported that elementary school students' scientific literacy remains at a moderate to low level, particularly in the aspects of concept application and science process skills (Sari & Setiawan, 2020; Rahman et al., 2022; Yulianti et al., 2021). These findings indicate that conventional science learning has not fully facilitated students in connecting scientific concepts with real-life contexts, thus highlighting the need for more contextual and innovative learning approaches. At the same time, advances in digital technology have demonstrated strong potential in creating interactive learning environments that align with the characteristics of 21st-century learners (Hidayah et al., 2020; Kurniawati et al., 2023). In parallel, the integration of local wisdom in science learning has been shown to enhance contextual relevance and support students' character development (Nurhayati & Wahyudi, 2023; Sulastri et al., 2021). Indonesia possesses abundant local wisdom that can be utilized as meaningful learning resources in biology education, including traditional knowledge related to medicinal plants, farming systems, conservation practices, and human-nature interactions. Integrating local wisdom into biology learning not only facilitates students' conceptual understanding but also fosters cultural appreciation and environmental awareness (Marlina, 2020). This perspective is consistent with contemporary science education frameworks emphasizing that project-based and inquiry-oriented learning in elementary classrooms plays a crucial role in fostering students' scientific literacy, conceptual understanding, and engagement with authentic scientific practices (Krajcik & Czerniak, 2023).

Several studies in *Jurnal Penelitian Pendidikan IPA (JPPIPA)* have demonstrated that digital-based and project-oriented science learning can significantly enhance students' engagement and scientific literacy when compared to traditional instructional approaches (Pratiwi et al., 2022; Suryani et al., 2022). However, these studies also highlight that the integration of digital technology alone is insufficient without contextual learning resources that are closely related to students' daily environments.

Moreover, the development of educational technology – such as augmented reality (AR), interactive e-modules, and gamification – has been proven to increase student engagement and facilitate the

understanding of abstract biological concepts (Putra & Dewi, 2022; Santoso & Jatmiko, 2022). For instance, AR enables students to observe plant structures or human organs in three dimensions, supporting deeper conceptual visualization. Despite this potential, the use of digital technology in elementary schools remains limited, often restricted to simple presentations or basic internet access. Teachers rarely integrate interactive digital media with local environmental resources. This situation reveals a pedagogical gap: although both local wisdom and digital technology hold significant potential, their systematic integration in elementary biology learning is still minimal.

Research published in *JPPIPA* further emphasizes the importance of integrating local wisdom into science learning to promote contextual understanding and character development (Rahmawati et al., 2021; Suryani et al., 2022). Nevertheless, most existing studies have focused on either digital learning or local-wisdom-based instruction separately, indicating a research gap in developing an integrated hybrid learning model that simultaneously enhances scientific literacy and ecological character at the elementary level.

Addressing this gap is crucial, particularly as biology education at the elementary level plays a strategic role in developing students' ecological character, including environmental awareness, responsibility, and sustainable living habits (Wulandari, 2021). Environmental sustainability has become a critical global issue, and early education is essential for cultivating environmentally responsible future generations. Studies indicate that learning based on local wisdom related to environmentally friendly practices can significantly strengthen students' ecological awareness and behavior (Pramono & Lestari, 2023).

As a response to these challenges, this study develops a Hybrid Biology Learning Model that integrates project-based learning, local wisdom content, and interactive digital technology. The project-based learning approach is chosen because it effectively promotes critical thinking, problem-solving, and collaboration skills (Wahyuni et al., 2018). The novelty of this research lies in the systematic integration of local wisdom and digital technology within a hybrid instructional model that simultaneously targets scientific literacy and ecological character at the elementary school level. Unlike previous studies that focused on either digital learning or local-wisdom-based instruction separately, this study combines both elements through a Design-Based Research approach to produce a validated, practical, and effective learning model.

Although numerous studies have reported the effectiveness of digital technology-based learning in improving students' engagement and conceptual

understanding, most of these studies focus primarily on technological aspects without integrating local wisdom as a contextual foundation of learning. Conversely, research on local wisdom-based science learning has largely emphasized character development and contextual understanding but has rarely incorporated interactive digital technology to support visualization and learning interactivity. In addition, previous studies predominantly examined these approaches at the secondary or higher education levels, while empirical research at the elementary school level remains limited, particularly those addressing both cognitive and affective outcomes simultaneously.

Furthermore, existing studies tend to employ experimental or quasi-experimental designs that focus on measuring learning outcomes, rather than using a Design-Based Research (DBR) approach that systematically develops, refines, and validates an instructional model through iterative implementation. As a result, there is a lack of comprehensive learning models that integrate local wisdom and digital technology within a hybrid framework, are empirically tested at the elementary level, and are explicitly designed to strengthen scientific literacy and ecological character concurrently. This gap highlights the need for a learning model that not only improves academic achievement but also fosters environmental awareness through culturally relevant and technologically supported learning experiences.

Based on the identified research gap, the novelty of this study lies in the development and implementation of a Hybrid Biology Learning Model that systematically integrates local wisdom, project-based learning, and interactive digital technology within a Design-Based Research framework at the elementary school level. Unlike previous studies that examine these components separately, this study combines them into a single, coherent learning model that is contextual, technology-supported, and character-oriented.

Moreover, this study contributes novel empirical evidence by simultaneously examining the model's effectiveness in enhancing students' scientific literacy and strengthening their ecological character, two outcomes that are rarely investigated together in elementary science education research. By embedding local environmental practices into digitally supported project-based activities, the proposed model offers an innovative approach that bridges cultural relevance and 21st-century learning demands. Therefore, this study provides both theoretical contributions to the development of contextual science learning models and practical implications for elementary school teachers seeking to implement meaningful, technology-enhanced biology learning grounded in local wisdom.

This research is particularly important in the context of the Merdeka Curriculum, which emphasizes contextual, project-based learning and the development of 21st-century competencies. Furthermore, post-pandemic educational transformation requires learning models that are both digitally responsive and contextually grounded. Therefore, this study aims to develop a hybrid biology learning model that integrates local wisdom and digital technology, to implement the model in elementary biology learning, and to analyze its effectiveness in enhancing students' scientific literacy and ecological character. The findings of this study are expected to contribute theoretically to the advancement of innovative science learning models and practically to provide elementary school teachers with a contextual, effective, and applicable instructional alternative.

Method

This study employed a Design-Based Research (DBR) approach, which is categorized under the Research and Development (R&D) model. This approach was chosen because it aligns with the research objective to develop a Hybrid Biology Learning Model based on local wisdom and digital technology that is valid, practical, and effective in strengthening scientific literacy and students' ecological character at the elementary level. The DBR approach was implemented through a series of stages, including needs analysis, model design, development of learning tools, limited implementation, evaluation, revision, and field testing.



Figure 1. Flowchart of the design-based research (DBR) stages

The research subjects were 32 fifth-grade students (17 male and 15 female) from SD Negeri 28 Bireuen. The fifth grade was selected based on the consideration that students at this level possess sufficient reading, writing, and basic science comprehension skills to participate in project-based learning activities. The research site was chosen because the school is located in an area rich in local wisdom that can serve as a contextual source for biology learning, such as the use of medicinal plants, traditional conservation practices, and local ecological knowledge. In addition to students, the class teacher and local community figures with expertise in local wisdom were also involved as informants to enrich the learning content and ensure the contextual relevance of the developed materials.

The stages of the Design-Based Research (DBR) in this study consisted of six main phases. First, needs analysis, in which the researcher conducted preliminary surveys with teachers and students to identify the existing conditions of biology learning. Second, model design, which involved creating the design of the Hybrid Learning Model by integrating elements of local wisdom and digital technology. Third, development of learning tools, including the preparation of lesson plans (RPP), digital student worksheets (LKPD), and interactive media based on augmented reality. Fourth, limited implementation, where the model was tested in a small class setting to observe its initial effectiveness. Fifth, evaluation and revision, conducted based on feedback from teachers, students, and experts to refine the model. Finally, the sixth stage was field testing, aimed at validating the overall effectiveness and practicality of the developed model in a real classroom context.

Data collection was carried out using various techniques. Observation was employed to identify the initial conditions of biology learning, students' classroom activities, and ecological behaviors displayed before the implementation of the model. Interviews were conducted with teachers and local community figures to identify potential aspects of local wisdom that could be integrated into biology learning. The scientific literacy test consisted of 20 multiple-choice questions with indicators covering the understanding of biological concepts, science process skills, and the application of concepts in daily life. The test was developed based on scientific literacy indicators aligned with PISA standards and the elementary school curriculum. An ecological character questionnaire was administered to assess students' levels of environmental awareness, responsibility, and eco-friendly habits. The questionnaire utilized a Likert scale with indicators measuring attitudes, values, and ecological behaviors. Documentation was used to collect supplementary data, including photographs of activities, field notes, learning

tools, and students' work results. The scientific literacy test instrument underwent content validity testing through expert judgment, while its reliability was measured using Cronbach's Alpha, yielding a coefficient of 0.82, which falls under the high category. The ecological character questionnaire also demonstrated reliability with an Alpha coefficient of 0.79, indicating satisfactory internal consistency. Qualitative analysis was reinforced through data triangulation, involving teacher interviews, observation notes, and documentation. This approach ensured that the collected data were scientifically valid and credible.

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The data obtained were analyzed using both quantitative and qualitative methods. Quantitative analysis was applied to the results of the scientific literacy test and the ecological character questionnaire. The data were analyzed using the N-Gain test to determine the level of improvement in students' abilities after participating in the learning process (based on the classification: low < 0.30, medium 0.30–0.70, and high > 0.70) (Pratiwi et al., 2022), as well as the t-test to examine the significance of differences between pre- and post-implementation conditions within the same group (Field, 2018). Qualitative analysis was used to process data obtained from interviews, observations, and documentation through the stages of data reduction, data display, and conclusion drawing. Furthermore, the validity of the model was assessed through expert validation involving biology education experts, educational technology specialists, and elementary school teachers. The practicality of the model was evaluated based on the implementation feasibility observed during the learning process and responses

from both teachers and students. The effectiveness of the model was determined through improvements in students' scientific literacy and the strengthening of their ecological character. Through this mixed-method approach, the study aims not only to produce a theoretically sound learning model but also one that is practical for classroom implementation and effective in enhancing the quality of contextual biology learning in accordance with current educational needs.

Result and Discussion

The results of this study indicate that the hybrid biology learning model integrating project-based learning, local wisdom, and digital technology significantly improved elementary students' scientific literacy, particularly in the aspects of conceptual understanding, science process skills, and the application of scientific concepts in daily life. This finding is consistent with previous studies published in Jurnal Penelitian Pendidikan IPA (JPPIPA), which reported that contextual and project-based science learning effectively enhances elementary students' scientific literacy (Sari & Setiawan, 2020; Rahman et al., 2022; Yulianti et al., 2021). At the international level, similar findings have been reported, indicating that hybrid and inquiry-oriented science learning environments support students' scientific reasoning and real-world application of scientific knowledge (Dori et al., 2021). Similar results have also been reported in international Scopus-indexed journals, indicating that project-based and digitally supported learning promotes critical thinking and scientific reasoning among elementary students (Hidayat & Prasetyo, 2020; Putra & Dewi, 2022). These findings are in line with recent national empirical evidence showing that hybrid learning models in elementary science education significantly enhance students' learning outcomes and engagement by combining face-to-face instruction with structured digital learning activities (Iskandar & Pramono, 2024). The improvement in students' scientific literacy before and after the implementation of the Hybrid Model is presented in Table 1.

Table 1. Improvement of Students' Scientific Literacy

Aspects of Scientific Literacy	Pre-test	Post-test	N-Gain	Category
Conceptual Understanding	56.2	82.5	0.60	Moderate
Science Process Skills	54.8	80.9	0.58	Moderate
Application of Concepts	55.1	81.8	0.61	Moderate
Average	55.4	81.7	0.60	Moderate

The significant increase in students' scientific literacy, as indicated by the N-Gain score of 0.60

(moderate category), confirms that the hybrid learning approach provides meaningful learning experiences by

combining contextual learning resources with interactive digital media. A quasi-experimental study reported in *Education Sciences* demonstrated that hybrid science learning significantly improves students' scientific literacy and higher-order thinking skills through a balanced combination of online and face-to-face activities (Sáez-López et al., 2022). According to OECD (2019), scientific literacy involves not only mastering scientific concepts but also developing the ability to interpret data, evaluate evidence, and apply scientific knowledge in real-life contexts. This result is in line with recent findings showing that inquiry-based and digitally supported science learning significantly enhances elementary students' scientific literacy and engagement through active exploration and data interpretation activities (Kurniawati et al., 2023). The present findings support this framework, as students demonstrated substantial improvement in conceptual understanding, science process skills, and the application of biological concepts in everyday situations.

More specifically, the improvement in conceptual understanding from 56.2 to 82.5 highlights the important role of local wisdom in contextualizing biological concepts. International research on culturally responsive science education confirms that embedding cultural and local contexts into science instruction enhances students' conceptual understanding and learning engagement (*Journal of Research in Science Teaching*) (Bang et al., 2021). The integration of local materials such as medicinal plants and traditional conservation practices enabled students to connect abstract concepts with their immediate environment. This finding is in line with Nurhayati et al. (2023) and Sulastri et al. (2021), who reported in JPPIPA that learning integrated with local wisdom significantly improves students' conceptual understanding and environmental awareness. International literature also confirms that culturally responsive and contextual science learning enhances students' cognitive engagement and conceptual comprehension (Suastra, 2017; Rahman et al., 2023).

The improvement in science process skills from 54.8 to 80.9 indicates that the project-based component of the Hybrid Model effectively promoted inquiry, observation, data collection, and reasoning skills. This result supports the findings of Wahyuni et al. (2018), who reported that Project-Based Learning fosters students' critical thinking and collaboration skills. This finding is supported by recent Scopus-indexed research in *Research in Science Education*, which reports that project-based science learning significantly enhances elementary students' inquiry skills and scientific practices when learning tasks are authentic and problem-oriented (Chen & Yang, 2022). Consistent evidence from Scopus-indexed studies further suggests that inquiry-based digital learning significantly

enhances students' scientific reasoning and problem-solving abilities (Santoso & Jatmiko, 2022; Kurniawati et al., 2023).

In addition to cognitive outcomes, this study revealed a substantial strengthening of students' ecological character. The increase in ecological character scores from 68.35 (fair) to 86.94 (very good) confirms that integrating local wisdom into biology learning effectively fosters environmental awareness, ecological responsibility, and eco-friendly habits. This result is consistent with recent international studies published in *Sustainability*, which demonstrate that sustainability-oriented science education at the elementary level effectively promotes pro-environmental attitudes and ecological behavior among students (Leicht et al., 2022). Similar findings were reported in JPPIPA by Suryani et al. (2022) and Rahmawati et al. (2021), who emphasized that local-wisdom-based science learning promotes sustainable attitudes and behaviors among elementary students. International studies also support that environmental education integrated with digital media strengthens students' ecological values and pro-environmental behavior (OECD, 2019; Pramono & Lestari, 2023). This finding reinforces previous evidence that science learning integrated with local wisdom effectively improves students' conceptual understanding while simultaneously fostering environmental awareness and ecological character in elementary school contexts (Nurhayati & Wahyudi, 2023). The comparison of students' ecological character scores before and after the intervention is presented in Figure 2.

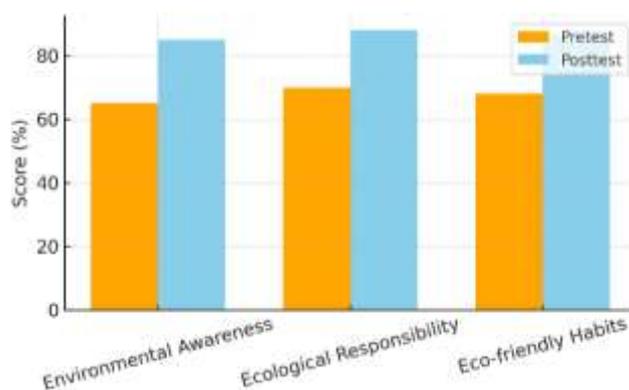


Figure 2. Comparison of students' ecological character scores

Furthermore, the integration of interactive digital technology, such as augmented reality and digital modules, contributed to increased student engagement and deeper conceptual understanding. Digital visualization enabled students to observe biological structures and processes that are difficult to explore directly. A recent meta-analysis published in *Computers & Education* confirms that augmented reality-based

science learning significantly improves students' conceptual understanding and motivation, particularly in elementary and secondary education contexts (Garzón et al., 2021). This finding aligns with Putra et al. (2022) and Hidayah et al. (2020), who reported that interactive digital media enhances students' motivation and facilitates the visualization of abstract biological concepts. The synergy between local wisdom and digital technology within the Hybrid Model thus provides a powerful learning environment that is both culturally relevant and technologically responsive.

Overall, the findings confirm that the Hybrid Biology Learning Model provides an effective learning framework that integrates cognitive, affective, and contextual dimensions of science learning. Theoretically, these findings extend existing science education models by demonstrating that the integration of local wisdom and digital technology can simultaneously enhance cognitive and affective learning outcomes at the elementary level. By combining project-based learning, local wisdom, and digital technology, the model aligns with current global trends in science education that emphasize collaborative inquiry and student-centered learning processes (Bell et al., 2022). International literature in Science Education emphasizes that integrative learning models are essential for preparing students with scientific literacy and sustainability competencies required in the 21st century (Evagorou et al., 2022; Leicht et al., 2022).

Conclusion

Based on the results of this study, it can be concluded that the Hybrid Biology Learning Model integrating local wisdom and digital technology is effective in improving elementary school students' scientific literacy and strengthening their ecological character. The improvement in scientific literacy, as indicated by an N-Gain value of 0.60 (moderate category), demonstrates that the model supports students in understanding biological concepts, developing scientific process skills, and applying scientific knowledge in everyday contexts. In addition, students' ecological character showed a substantial improvement from the "fair" to the "very good" category, particularly in terms of environmental awareness, ecological responsibility, and eco-friendly habits. These findings suggest that the integration of contextual local wisdom with interactive digital technology can serve as a promising learning approach to enhance both cognitive and affective learning outcomes at the elementary level. The model was also confirmed to be valid, practical, and feasible based on expert validation, teacher evaluations, and positive

student responses, indicating its potential applicability beyond the research setting. From a practical perspective, this Hybrid Learning Model provides elementary school teachers with an alternative instructional strategy that is contextual, engaging, and aligned with 21st-century learning demands. Teachers are encouraged to adapt the model by incorporating local wisdom relevant to their own regions to strengthen students' connection with their local environment while supporting science learning objectives. Furthermore, future research is recommended to implement and evaluate this model at different educational levels or in other subject areas to further examine its effectiveness and broaden its contribution to science education.

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Author Contributions

Conceptualization, T.L. and A.; methodology, T.L. and A.; funding acquisition, T.L. and A.; formal analysis, T.L. and A.; investigation, T.L. and A.; resources, T.L., A., F.R., M.F., and F.M.N.; data curation, T.L. and A.; writing—original draft preparation, T.L. and A.; writing—review and editing, F.R., M.F., and F.M.N.; supervision, F.R., M.F., and F.M.N.; project administration, F.R. and M.F.; validation, F.R., M.F., and F.M.N. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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