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DEEP LEARNING-BASED BIOLOGY LEARNING WITH ETHNOPEDAGOGY AND LOCAL WISDOM TO SUPPORT SUSTAINABLE DEVELOPMENT GOALS

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ABSTRACT

This study aims to implement a deep learning-based Biology learning model that integrates ethnopedagogical approaches and local wisdom values to support the achievement of the Sustainable Development Goals (SDGs), specifically SDG 4 (quality education), SDG 13 (climate change), and SDG 15 (preservation of terrestrial ecosystems). The research method uses a quantitative approach with a pre-experimental design (one-group pretest-posttest) because the data are preliminary and the study is still in the research and development stage. The study subjects were students from a private high school in Bandung City, which has a rich local culture and high biodiversity. Data collection instruments included cognitive tests, affective and psychomotor observation sheets, and an ecological awareness questionnaire. The study found a significant increase in students' cognitive, affective, and psychomotor skills following the implementation of the learning model. In addition, culture-based learning succeeded in fostering meaningful connections between Biology concepts and traditional community practices. This study concludes that the implementation of the learning model shows great potential to shape students who are ecologically aware and rooted in cultural values. The integration of immersive learning and ethnopedagogy offers an innovative alternative in biology education that is locally relevant yet globally impactful. This research is still in its developmental stage and therefore uses pre-experimental methods.

Keywords: learning models; biology; deep learning, ethnopedagogy; local wisdom; SDGs; sustainable education

INTRODUCTION

21st-century education requires students not only to master scientific knowledge but also to develop critical thinking, problem-solving skills, and sustainability awareness aligned with the Sustainable Development Goals (SDGs). However, in many educational contexts, particularly in biology learning, students' conceptual understanding remains superficial and fragmented (Herlanti et al., 2019). Numerous studies indicate that students often memorize biological facts without deeply understanding the underlying concepts or their relevance to real-life environmental and social issues (Imaduddin et al., 2024). As a result, biology learning tends to focus on procedural knowledge rather than meaningful conceptual understanding, limiting students' ability to apply biological knowledge to real-world problems such as biodiversity conservation, environmental sustainability, and human health (Nuralisa et al., 2025).

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One of the main causes of this problem is the dominance of teacher-centered and content-oriented learning approaches that emphasize factual knowledge rather than deep conceptual exploration (Ardianti et al., 2025). Such approaches often neglect the development of higher-order thinking skills and reflective learning processes that are essential in modern science education (Imaduddin et al., 2024). Consequently, students struggle to connect biological concepts with real phenomena in their surrounding environment, leading to low engagement and limited scientific literacy (Irwandi et al., 2025).

Another significant issue is the lack of contextualization of biology learning within students' cultural and environmental realities (Rosyidah et al., 2025). Science education in Indonesia is frequently influenced by Western scientific frameworks that are not always connected to local cultural knowledge or traditional ecological practices (Faisal & Martin, 2019). This disconnect reduces the relevance of learning experiences for students and weakens their ability to relate biological concepts to their everyday lives (Sugara & Sugito, 2022). In fact, local knowledge systems—such as traditional medicinal plants, indigenous agricultural practices, and ecological beliefs—contain valuable biological insights that can enrich science learning and strengthen students' cultural identity (Istiningsih & Dharma, 2025).

According to Sukrin & Ihlas (2025), ethnopedagogy offers an alternative approach to address this issue by integrating local cultural knowledge into educational practices. Through ethnopedagogical perspectives, traditional knowledge, local wisdom, and community practices can serve as authentic learning resources that help students understand scientific concepts in meaningful contexts (Vilmala et al., 2025). In biology education, integrating ethnopedagogy allows students to explore scientific concepts through familiar cultural phenomena, thereby improving both conceptual understanding and cultural awareness (Hakim et al., 2025).

At the same time, advances in digital technology have introduced new opportunities for improving science learning (Nasution et al., 2024). Deep learning-based educational technologies have the potential to support personalized and adaptive learning environments that facilitate deeper conceptual engagement and complex problem-solving (Alatas & Yakin, 2021; Jumini et al., 2022). In biology education, such technologies can analyze learning patterns and provide adaptive materials that help students better understand complex biological systems (Syadella et al., 2025). Despite these developments, current research tends to examine these approaches separately (Hosain et al., 2024). Some studies focus on integrating artificial intelligence or deep learning technologies into education to improve personalized learning (Arsyad et al., 2025), while others emphasize the role of ethnopedagogy in embedding cultural values in science education (Rissi & Sinaga, 2025). However, very few studies integrate deep learning technology, ethnopedagogical approaches, and local wisdom simultaneously in biology education, particularly to support Education for Sustainable Development (ESD) and the achievement of the SDGs (Mangubat & Mangubat, 2025).

This gap is particularly important in countries like Indonesia, which possess rich biodiversity and diverse cultural knowledge systems (Yanee et al., 2025). According to Muniisvaran et al. (2025), without meaningful integration between scientific knowledge, technological innovation, and local cultural values, biology learning risks remaining abstract and disconnected from students' real-world experiences. Therefore, a learning framework that integrates deep learning with ethnopedagogy and local wisdom may offer a more holistic approach to enhancing students' conceptual understanding, critical thinking skills, and ecological awareness (Reffiane et al., 2020).

This study aims to design and evaluate a deep learning-based biology learning model that integrates ethnopedagogy and local wisdom to enhance students' conceptual understanding of biology while promoting sustainability-oriented values aligned with the SDGs, particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land). By bridging digital innovation with culturally contextual pedagogy, this research is expected to contribute both theoretically to science education research and practically to the development of sustainable and culturally responsive biology learning in Indonesia (Zeinalipour et al., 2023).

METHODS

This study employed a quantitative approach using a pre-experimental design, specifically the One–Group Pretest–Posttest Design (Creswell & Creswell, 2018). The design was selected to examine the initial effectiveness of a deep learning-based biology learning model integrating ethnopedagogical approaches and local wisdom values in improving students' conceptual understanding, ecological awareness, and SDG com-

petencies (Zan & Asrizal, 2024). Although the primary objective of this research is to develop a biology learning model, the current study represents the initial stage of a broader Research and Development (R&D) process (Yaniawati, 2020). Therefore, the pre-experimental design was used as a preliminary testing phase to obtain an initial evaluation of the effectiveness of the developed model before conducting more rigorous experimental validation (Sugiyono, 2017).

According to Aqib (2019), in the One Group Pretest–Posttest Design, a single group of students receives the learning intervention. Students are given a pretest before implementing the learning model to assess their initial abilities. After the intervention, a posttest is administered to measure improvements in learning outcomes. The difference between pretest and posttest scores indicates the effectiveness of the developed learning model (Muhajir, 2000). Although this design does not involve a control group and therefore has lower internal validity than true experimental designs, it remains useful for evaluating the initial impact of educational innovations in real classroom contexts (Creswell, 2019).

The learning model developed in this study is referred to as the Deep Learning–Ethnopedagogy Biology Learning Model (DEBL Model). This model integrates three main components: the deep learning approach, the ethnopedagogical approach, and the integration of local wisdom. The deep learning approach emphasizes the development of conceptual understanding, higher-order thinking skills, reflective learning, and students' problem-solving abilities. Meanwhile, the ethnopedagogical approach incorporates cultural knowledge and local traditions as contextual learning resources, allowing students to connect scientific concepts with their sociocultural environment. In addition, integrating local wisdom draws on local ecological knowledge, such as traditional medicinal plants, indigenous agricultural practices, and community-based biodiversity management systems. Through this integration, biology learning becomes more meaningful, contextual, and relevant to students' real-life experiences.

The instructional syntax of the DEBL model consists of five learning stages. The first stage is Contextual Exploration, in which students explore biological phenomena related to local culture and environmental practices. The second stage is Conceptual Investigation, in which students analyze biological concepts through inquiry-based learning supported by digital resources. The third stage, Cultural Reflection, encourages students to connect biological concepts with local cultural knowledge and traditional ecological practices. The fourth stage is Ecological Problem Solving, in which students collaboratively analyze environmental problems related to sustainability and the Sustainable Development Goals (SDGs). The final stage is the Sustainability Action Project, in which students design and implement projects that address local environmental problems using biological concepts and local wisdom. Through these stages, the learning model aims to promote contextual, reflective, and sustainability-oriented learning experiences.

This model is designed to contribute to achieving the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land). By integrating scientific knowledge with local cultural values and sustainability principles, the model is expected to support biology learning that not only improves students' conceptual understanding but also fosters ecological awareness and sustainability-oriented competencies.

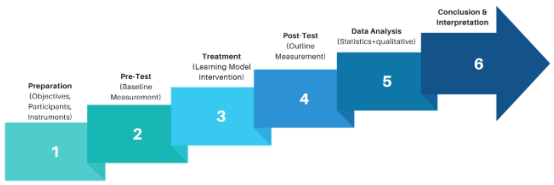

Figure 1. Research Flowchart

The study was conducted at a private senior high school in Bandung, West Java, Indonesia, which has basic technological infrastructure and supports digital learning innovation. The research location was selected based on several considerations, including the availability of digital learning facilities, the openness of the school curriculum to integrating local wisdom into learning activities, and the readiness of teachers and students to adopt innovative technology-based learning approaches. The research was conducted over three months, from August to October 2024.

The participants in this study were 32 eleventh-grade students from the Mathematics and Natural Sciences program studying biology topics related to ecosystems, biodiversity, and environmental conservation, which are closely aligned with the values and objectives of the SDGs (Zhuang et al., 2023). The participants were selected using a purposive sampling technique, based on criteria such as curriculum relevance, student readiness to participate in innovative learning activities, and institutional support from the school.

The data obtained were analyzed using descriptive and inferential quantitative approaches. Techniques used included normality and homogeneity tests to ensure the data could be analyzed parametrically, paired sample t-tests to determine significant differences between the pretest and posttest ($\alpha = 0.05$), and N-Gain calculations.

Deep learning data was analyzed using a clustering visualization of student responses. This was used to map groups based on levels of understanding and misconceptions using Matplotlib and Seaborn (Farhoudi & Setayeshi, 2021). Qualitative data, consisting of interviews and reflections, were analyzed using open coding and thematic categorization techniques.

RESULTS AND DISCUSSION

To evaluate the effectiveness of the developed learning model, students' conceptual understanding of biology concepts related to ecosystems, biodiversity, and conservation was measured using pretest and posttest assessments. The comparison of students' scores before and after the learning intervention is presented in Table 1.

Table 1. Comparison of Pretest and Posttest Scores

Aspect	Average	Standard Deviation (SD)
Pretest	58.6	10.4
Posttest	84.3	8.7

Figure 2 illustrates a clear increase in students' average scores after the learning intervention.

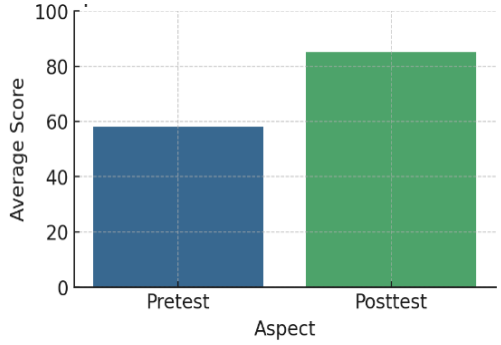

Figure 2. Comparison of Pretest and Posttest Scores

The average pretest score was approximately 58, reflecting students' initial understanding of the material before the learning model was implemented. After the intervention, the average posttest score increased to approximately 85, indicating that the learning model significantly improved students' comprehension of biological concepts. The improvement of 25.7 points between the pretest and posttest scores demonstrates that integrating deep learning strategies with ethnopedagogical approaches can effectively enhance students' conceptual understanding (Yang et al., 2023). These findings support previous studies showing that student-centered learning approaches can significantly improve conceptual comprehension in science education (Dirgantari & Cahyani, 2023).

From Vygotsky's social constructivist perspective, learning occurs through social interaction and the construction of knowledge within cultural contexts (Wardani et al., 2023). In this study, students were actively engaged in collaborative learning, discussions, and the contextual exploration of local environmental practices. These interactions allowed students to construct new knowledge by linking scientific concepts with real-life cultural experiences (Rosyidah et al., 2025). Such processes align with Vygotsky's concept of the Zone of Proximal Development (ZPD), where learners develop deeper understanding through interaction with peers and teachers who provide guidance and scaffolding (Vygotsky, 1978; Taufiq & Rokhman, 2020).

The analysis of a classification-based deep learning model (using TensorFlow and Keras) on student responses showed a pattern of increasing conceptual understanding across low-to-high clusters. Of the 32 student responses analyzed, 72% moved to a high-level category after treatment (Giakoumis, 2017). Visualization using t-SNE showed that student responses became more concentrated in the "correct concept" after learning, demonstrating the method's effectiveness in addressing common misconceptions in ecosystem topics (Cheng et al., 2021).

The results of the study indicate that a deep learning-based biology learning model, grounded in an ethnopedagogical approach and local wisdom values, has a significant impact on improving student learning outcomes and awareness of the Sustainable Development Goals (SDGs) (Wang et al., 2022). The increase in pretest to posttest scores, from 58.6 to 84.3, a 25.7-point rise, reflects a substantial improvement in cognitive understanding. This finding aligns with Tindowen et al. (2017), who demonstrated that applying the Discovery Learning model in conjunction with Lesson Study can increase essay scores from 37.5 to 77.0, with a significant effect (Cohen's $d = 3.3$).

The increase in SDG awareness scores was also evident, with an average increase of 1.1 points on the Likert scale across the three dimensions measured: ecological, social, and economic. These results indicate that integrating local context and cultural values can enhance the relevance of learning and foster students' global awareness (Sumardi et al., 2020). MDPI (2021) also showed similar results, indicating that a design-based learning model significantly increased students' motivation and awareness. Furthermore, this learning model successfully established a connection between students' cognitive and affective aspects, which is the core of the Education for Sustainable Development approach. Compared to the scientific argumentation model, which yielded a gain score of 0.49 (Mou, 2023), the model used in this study yielded an N-Gain of 0.62, indicating greater effectiveness.

The implications of these findings suggest that technology-based active learning grounded in local culture not only strengthens conceptual understanding but also shapes students' character and attitudes toward global issues. Therefore, this approach is highly recommended for widespread implementation across educational levels, particularly in areas with rich local cultures (Hong et al., 2022). By adopting the principles of deep learning and ethnopedagogy, teachers can create a meaningful, personalized, and sustainable learning environment for students.

The increase in pretest-to-posttest scores and N-Gain values indicates that the developed biology learning model is effective in improving students' conceptual understanding. The integration of deep learning enables students to receive automated, data-driven feedback, helping them identify misconceptions in real-time (Janiesch et al., 2021). This reinforces previous findings that AI technology can support personalized learning in science (Ming et al., 2022).

The integration of an ethnopedagogical approach also encourages strengthening the local context in learning, making the material easier to understand because it is linked to students' everyday experiences (Yang, 2023). The integration of an ethnopedagogical approach also strengthens the use of local context in learning, making biological concepts easier for students to understand because the material is directly connected to their everyday experiences and cultural environment (Hikmah Syafiulia et al., 2025). From Vygotsky's social constructivist perspective, knowledge is constructed through social interaction and engagement with cultural tools within a specific sociocultural context (Kawuri et al., 2019). In this study, the use of local wisdom—such as traditional ecological practices, medicinal plants, and community-based environmental management—serves as a cultural mediator, helping students interpret scientific concepts through familiar experiences (WHO, 2022). Through collaborative discussions, group projects, and teacher guidance, students interact with peers and instructors to construct new understandings, reflecting the process of learning within Vygotsky's Zone of Proximal Development (ZPD). In this process, teachers provide scaffolding by guiding students to connect biological concepts with local cultural knowledge, enabling them to develop a deeper conceptual understanding gradually. Therefore, integrating ethnopedagogy not only contextualizes learning but also supports the sociocultural process of knowledge construction emphasized in Vygotsky's theory, in which learning becomes more meaningful through interaction among learners, culture, and the learning environment.

The use of local wisdom values in learning increases students' awareness of sustainability principles. For example, when students learn about water conservation, they are connected to traditional practices such as "Leuwi" and "Sumur Resapan" (absorption wells), which are still used in Sundanese indigenous communities. This contextual experience makes learning more relevant and meaningful (Tabrani & Amin, 2023).

This connection aligns with the SDGs' education pillar, which emphasizes transformative learning grounded in local values to foster active citizen participation in sustainable development (Böhmer, 2023). Furthermore, the use of local culture as a learning medium supports the preservation of national identity values that are eroding under globalization (Mumcu et al., 2023). To evaluate the intervention's effectiveness in increasing awareness of the Sustainable Development Goals (SDGs), participants' awareness was measured across three dimensions: ecology, social, and economy. The average scores before and after the intervention are presented in Table 2.

Table 2. Increase in SDGs Awareness

Dimension	Before (Average)	After (Average)
Ecology	3.0	4.1
Social	3.2	4.3
Economy	3.1	4.2

Table 2 shows that participants' awareness in all three SDGs dimensions increased after the intervention. Awareness in the ecology dimensi-

on rose from 3.0 to 4.1, in the social dimension from 3.2 to 4.3, and in the economy dimension from 3.1 to 4.2. These results indicate that the intervention was effective in enhancing participants' understanding and concern for sustainability issues across various aspects.

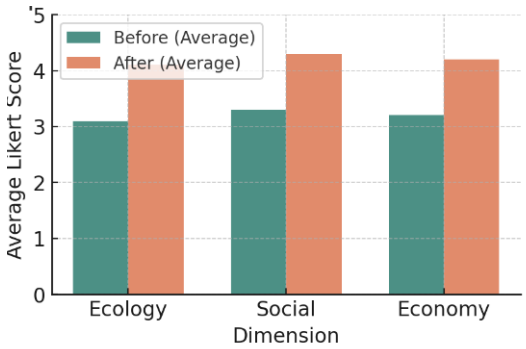

Figure 3. The Increase in SDGs Awareness

The results of the study demonstrate that a deep learning-based biology learning model, combined with an ethnopedagogical approach and local wisdom values, significantly enhances learning outcomes and increases students' awareness of the Sustainable Development Goals (SDGs). The increase in pretest to posttest scores, from 58.6 to 84.3, a 25.7-point rise, reflects a substantial improvement in cognitive understanding.

This finding aligns with Miranda et al. (2021), who demonstrated that applying the Discovery Learning model in conjunction with Lesson Study can increase essay scores from 37.5 to 77.0, with a significant effect (Cohen's d = 3.3). The increase in SDG awareness scores was also evident, with an average increase of 1.1 points on the Likert scale across the three dimensions measured: ecological, social, and economic (Filho et al., 2024). These results indicate that integrating local context and cultural values can enhance the relevance of learning and foster students' global awareness. MDPI (2021) also showed similar results, indicating that a design-based learning model significantly increased students' motivation and awareness.

Furthermore, this learning model successfully connected students' cognitive and affective aspects by designing learning activities that engaged social interaction, cultural context, and meaningful experiences. According to Vygotsky's sociocultural learning theory, cognitive development occurs through social interaction and the use of cultural tools that shape the learning process (Chen et al., 2020). In this study, the integration of ethnopedagogical elements and local wisdom served as cultural mediators, helping students connect biological concepts to their real-life experiences. Through collaborative discussions, group projects, and contextual problem-solving activities, students not only developed conceptual understanding (cognitive domain) but also formed attitudes of environmental responsibility and sustainability awareness (affective domain). This process reflects Vygotsky's concept that learning is a socially mediated activity in which emotional engagement, cultural values, and interaction with others contribute to the development of higher mental functions. Therefore, integrating culturally contextual learning experiences enables students to simultaneously construct scientific knowledge and develop positive attitudes toward environmental sustainability, which is the core of the Education for Sustainable Development approach (Saini et al., 2023). Compared to the scientific argumentation model, which yielded a gain score of 0.49 (Li et al., 2020), the model used in this study yielded an N-Gain of 0.62, indicating greater effectiveness.

These findings imply that technology-based active learning grounded in local culture not only strengthens conceptual understanding but also shapes students' character and attitudes towards global issues (Trinidad, 2025). Therefore, this approach is highly recommended for widespread implementation across educational levels, particularly in areas with rich local cultures. By adopting the principles of deep learning and ethnopedagogy, teachers can create a meaningful, personalized, and sustainable learning environment for students (Akmar et al., 2026). This strategy aligns with the Education for Sustainable Development (ESD) approach, which emphasizes action-oriented, interdisciplinary learning (Ruswendi et al., 2024). By developing projects that address local issues, students are more encouraged to act as change agents in their environment (O'Connor et al., 2022).

CONCLUSION

The study's results indicate that implementing this learning model significantly improved students' learning outcomes. This improvement is reflected in the increase in students' average scores from 58.6 in the pretest to 84.3 in the posttest, with an N-Gain of 0.62, indicating a moderate-to-high level of learning. In addition, students' awareness of sustainability issues also increased across the ecological, social, and economic dimensions of the SDGs. The findings suggest that integrating deep learning strategies with ethnopedagogical approaches and local wis-

dom can create a more contextual, meaningful, and culturally responsive learning environment. Therefore, this learning model has the potential to support the implementation of Education for Sustainable Development (ESD) in biology education, particularly in contexts where local cultural knowledge and environmental practices can be integrated into science learning. The model is recommended for broader application in biology classrooms to promote meaningful learning experiences that foster both scientific literacy and sustainability awareness among students.

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