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Deep Learning-Enhanced Discovery Learning: Impact on High School Students' Environmental Change Outcomes

Dwi Andini Putri[1], Agung Setia Batubara[2]
[1, 2] Department of Biology Education, Universitas Negeri Medan, Indonesia

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ABSTRACT

This study investigated the effect of the Discovery Learning model integrated with a Deep Learning approach on students' learning outcomes in the topic of Environmental Change and Conservation. A quasi-experimental design with a Non-equivalent Control Group was employed, involving 70 Grade X students at High School 1 Batang Kuis, Indonesia, divided equally into experimental ($n = 35$) and control ($n = 35$) groups. Instruments included 20 higher-order thinking (C4–C6) multiple-choice items administered as pretest and posttest. Data were analysed using the Mann–Whitney U test and Normalised Gain (N-Gain) through IBM SPSS Statistics. Results showed that posttest mean scores were significantly higher in the experimental class ($M = 89.57$, $SD = 7.51$) than in the control class ($M = 82.14$, $SD = 10.79$). The Mann–Whitney test yielded a significant difference ($U = 280.5$, $p = 0.03$), with the experimental group's mean rank (42.67) exceeding that of the control group (28.33). Furthermore, the experimental class achieved a high N-Gain category (0.78) compared to the moderate category of the control class (0.66). These findings demonstrate that the Discovery Learning–Deep Learning integration effectively promotes conceptual understanding and higher-order cognitive skills in biology education.

Corresponding Author:

Dwi Andini Putri,
Department of Biology Education, Universitas Negeri Medan, Indonesia
Email: dwiandiniputri774@gmail.com

1. INTRODUCTION

The imperatives of 21st-century education demand a paradigm shift from traditional instructional models toward holistic approaches that foster learner competencies across three interconnected domains: knowledge, attitudes, and skills (Sinclair, 2026). These domains constitute the cornerstone for cultivating productive, globally competitive, and critically engaged human resources equipped to navigate increasingly multifaceted socio-ecological challenges (Azzahra et al., 2023). In response, modern curricular reforms prioritize student-centered learning (SCL) principles, which conceptualize learners as active constructors of knowledge rather than passive recipients of information (Bhardwaj et al., 2025). This theoretical reorientation redefines instructional design, placing inquiry-based, problem-driven, and discovery-oriented pedagogies at the forefront of contemporary educational practice (Morris, 2025).

Within biology education, this curricular aspiration becomes particularly crucial when addressing complex ecological concepts (Honra, 2026). Topics such as Environmental Change and Conservation (Perubahan dan Pelestarian Lingkungan Hidup) demand far more than rote memorization or surface-level content recall; they require higher-order cognitive processes, including systems thinking, causal reasoning, and the practical application of ecological principles to real-world environmental crises (Rahmawati et al., 2024). Cultivating ecological literacy necessitates pedagogical strategies that enable students to evaluate environmental degradation critically, analyze human-environment interactions, and formulate sustainable solutions within their immediate ecosystems (Koyama & Watanabe, 2023; Xiong et al., 2025).

Despite these clear curricular objectives, a substantial disconnect frequently persists between policy intent and classroom-level realities. Initial classroom observations conducted at High School 1 Batang Kuis, located in Deli Serdang Regency, exposed pronounced heterogeneity in student engagement and participatory dynamics across different learning groups. While certain groups of students actively posed questions and contributed to collaborative discussions, others exhibited marked passivity, requiring continuous motivational scaffolding and cognitive prompting from the teacher. These engagement disparities were acutely evident during instructional units covering environmental change and conservation, where students consistently struggled to translate theoretical environmental principles into systemic, higher-order understandings.

An examination of prevailing instructional practices at the school revealed a reliance on the direct instruction model, occasionally supplemented by teacher-led question-and-answer sessions and basic small-group discussions. This fundamentally teacher-centered paradigm proved inadequate for fostering deep conceptual mastery, as demonstrated by student academic performance failing to meet the established Learning Objective Attainment Criterion (Kriteria Ketercapaian Tujuan Pembelajaran/KKTP) threshold of 75. Furthermore, the limited diversity and integration of modern instructional media severely constrained opportunities for contextualized, authentic, and experiential learning, leaving students disengaged from the critical real-world relevance of environmental science.

To bridge this pedagogical gap, Discovery Learning (DL) offers a robust, constructivist-informed framework that transforms the traditional teacher-student dynamic. Positioning the educator as a strategic facilitator, DL guides learners through structured problem-solving activities where they actively explore phenomena, formulate hypotheses, and construct conceptual knowledge through guided inquiry (Mokoginta et al., 2025; Nur et al., 2025; Uri et al., 2024). A substantial body of empirical evidence highlights the efficacy of DL in boosting cognitive learning outcomes and fostering environmental literacy in biology education (Mansur & Bare, 2019; Ozdem-Yilmaz & Bilican, 2025). By embedding individual and collaborative inquiry directly into the learning sequence, DL encourages enduring schema construction and significantly improves cognitive retention (Schneider et al., 2022).

Complementing the structural mechanisms of DL, the Deep Learning (DeL) approach emphasizes meaningful, integrative cognitive engagement that explicitly links classroom subject matter to authentic real-world contexts and prior knowledge schemas (Agustin, 2026; Gawehn et al., 2016; Yan et al., 2022; Zhang et al., 2017). In stark contrast to surface-level learning—which is typically characterized by mechanical repetition, isolated facts, and short-term memory reliance—DeL cultivates metacognitive awareness, critical analytical thinking, and high transfer capacity (Sharifani & Amini, 2023; Talaei Khoei et al., 2023). This emphasis on deep conceptual processing makes DeL uniquely suited for application-heavy biological subjects like environmental conservation, where critical evaluation of multifaceted socio-ecological issues is essential (Ching et al., 2018; Goshisht, 2024; Sapoval et al., 2022; Webb, 2018).

The synthesis of Discovery Learning (DL) with the Deep Learning (DeL) approach establishes a theoretically coherent, synergistic, and practically viable pedagogical framework for upper-secondary biology instruction. While discovery learning provides the structured inquiry framework necessary for active exploration and autonomous knowledge construction, the deep learning approach ensures that the cognitive processing accompanying this inquiry transcends surface-level recall to achieve higher-order abstraction, metacognitive reflection, and authentic real-world application. By integrating these two complementary paradigms, educators can effectively bridge the gap between active scientific investigation and meaningful conceptual consolidation, thereby addressing the complex cognitive and affective demands inherent in secondary science curricula.

Despite the compelling theoretical alignment between these instructional methodologies, empirical investigations examining their combined implementation within the Indonesian senior high school context—particularly regarding complex ecological themes such as environmental change and conservation—remain notably scarce. This scarcity represents a significant gap in the literature, as the intersection of structured discovery and deep cognitive engagement is crucial for cultivating environmental literacy and critical problem-solving capacities in high school learners. Addressing this critical empirical void, the present study investigated the effect of the Discovery Learning model integrated with a deep learning approach on students' learning outcomes in the topic of environmental change and conservation.

2. METHOD

This study employed a quantitative quasi-experimental design with a Non-equivalent Control Group pre-test/post-test structure. This design was selected because intact classroom groups were utilised, precluding random assignment of individual participants. Although the design includes a control group and pre-and post-assessments, it does not fully eliminate the influence of extraneous variables (Campbell

& Stanley, 1963). Both groups received identical pre- and post-tests to enable controlled comparison of learning gains.

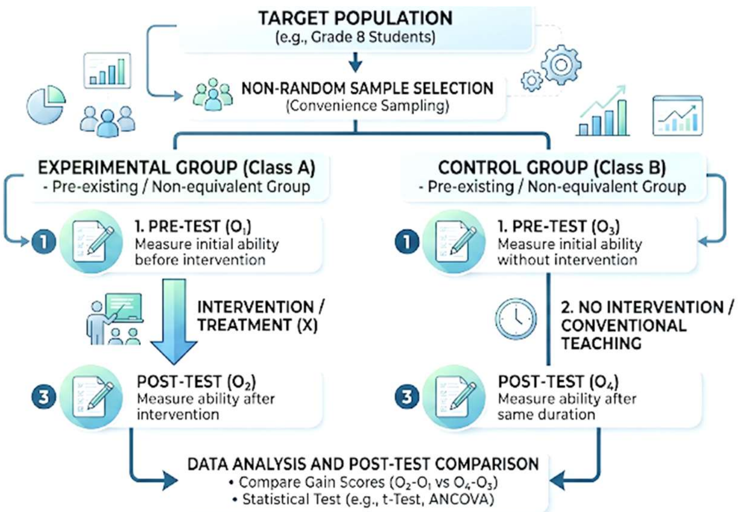

Figure 1. Non-equivalent Control Group Pre-Test/Post-Test Structure

The population comprised all Grade X students (N = 315) enrolled across nine classes at High School 1 Batang Kuis, Deli Serdang Regency, during the 2025/2026 academic year. Purposive sampling was used to select two classes with comparable student characteristics and the same biology teacher, thereby controlling for teacher variability as a confound. Class X-B (n = 35) was designated the experimental group and Class X-I (n = 35) served as the control group, yielding a total sample of 70 participants.

The experimental class received instruction using the Discovery Learning model integrated with the Deep Learning approach, operationalised across six phases: stimulation, problem identification, data collection, data processing, verification, and generalisation. Within this framework, the DeL approach was applied through activities that encouraged students to connect biological concepts to authentic environmental phenomena, engage in critical analysis of case studies, and collaboratively construct solutions to ecological problems. Instructional materials included a structured Teaching Module (*Modul Ajar/RPP*) and Student Worksheets (*LKPD*) developed specifically for this study.

The control class received instruction through the Direct Instruction model, which emphasised teacher-led explanations, structured note-taking, and guided question-and-answer sessions, consistent with prevailing practice at the school. All other instructional conditions (duration, teacher, assessment instruments, and content coverage) were held constant across groups. Three data collection techniques were employed: documentation, interview, and testing. Structured interviews were conducted with the biology teacher and selected students prior to the study to contextualise baseline instructional conditions and learner characteristics.

The primary instrument was a cognitive achievement test comprising 20 multiple-choice items calibrated to higher-order thinking skills at Bloom's Taxonomy levels C4

(Analysis), C5 (Evaluation), and C6 (Creation). The test was administered as a pretest (before instruction) and post test (after instruction). Items were validated through expert review and pilot testing prior to implementation. The test measured students' conceptual mastery of the Environmental Change and Conservation unit.

Descriptive statistics (mean, standard deviation, frequency distributions) were computed for both pretest and posttest scores. Because the Shapiro–Wilk normality tests indicated that not all data conformed to a normal distribution, the inferential comparison between experimental and control groups was conducted using the non-parametric Mann–Whitney U test, which is appropriate for comparing two independent groups when normality assumptions are violated. The significance threshold was set at $\alpha = 0.05$. Learning gain was quantified using the Normalised Gain (N-Gain) index, calculated as:

N-Gain = (Posttest Score − Pretest Score) / (Maximum Score − Pretest Score)

N-Gain values were interpreted using Hake's criteria: high (≥ 0.70), moderate (0.30–0.69), and low (< 0.30). All statistical analyses were performed using IBM SPSS Statistics version 25.

3. RESULTS AND DISCUSSION

Results

Pretest Scores: Baseline Equivalence

Prior to the administration of the instructional interventions, diagnostic evaluation established that both student cohorts possessed comparable baseline knowledge regarding Environmental Change and Conservation. Descriptive statistics revealed initial pretest mean scores of 40.86 ($SD = 18.04$) for the experimental group and 44.57 ($SD = 19.30$) for the control group. The negligible baseline disparity of 3.71 points confirm initial homogeneity between the two samples prior to treatment, thereby reinforcing the internal validity of the quasi-experimental design and minimizing potential confounding effects arising from pre-existing knowledge asymmetries.

In addition to equivalence between conditions, pre-intervention score distributions across both classes spanned a identical range from 10 to 75, reflecting widespread pre-instructional cognitive deficits on the subject matter. The concentration of initial scores at the lower end of the continuum underscores that many participants lacked competency-level mastery over complex ecological constructs, such as environmental degradation mechanisms and conservation dynamics. This widespread baseline inadequacy highlights the explicit necessity for targeted pedagogical scaffolding to elevate student conceptual understanding to required curricular standards.

Table 1. Pretest Score Distribution by Group

Control Class				Experimental Class			
Score	**f**	**Mean**	**SD**	**Score**	**f**	**Mean**	**SD**
10	1	44.57	19.30	10	1	40.86	18.04
15	2			15	3		
20	4			20	3		
25	2			25	4		
30	1			30	3		

Control Class				Experimental Class			
Score	**f**	**Mean**	**SD**	**Score**	**f**	**Mean**	**SD**
35	4			40	4		
40	2			45	3		
45	2			50	2		
50	2			55	4		
55	3			60	5		
60	4			65	1		
65	5			70	1		
70	1			75	1		
75	2			—			
Total	35			Total	35		

Post-test Scores: Post-Intervention Performance

Following the instructional intervention, quantitative assessments demonstrated substantial cognitive gains across both study conditions, though marked disparities emerged in their posttest achievement profiles. The experimental cohort exposed to the integrated Discovery Learning–Deep Learning (DL–DeL) model attained a superior posttest mean score of 89.57 ($SD = 7.51$), whereas the control cohort under conventional Direct Instruction recorded a posttest mean score of 82.14 ($SD = 10.79$). This outcome represents a statistically and pedagogically meaningful difference of 7.43 points favoring the experimental intervention, indicating that the combined instructional framework facilitated a more profound accumulation of content knowledge on Environmental Change and Conservation.

Beyond mean score differences, an analysis of score dispersion revealed key structural differences in learning equity and consistency between the two groups. Posttest performance in the experimental class was tightly concentrated within the upper achievement band ($75 - 100$), characterized by low variance and a smaller standard deviation, reflecting a uniform elevation of mastery across the student cohort. Conversely, the control group exhibited markedly greater variability and a broader score distribution ($55 - 100$), indicating that traditional direct instruction produced inconsistent learning gains and left a notable proportion of students below optimal competency levels.

Table 2. Posttest Score Distribution by Group

Control Class				Experimental Class			
Score	**f**	**Mean**	**SD**	**Score**	**f**	**Mean**	**SD**
55	1	82.14	10.79	75	2	89.57	7.51
60	2			80	5		
65	3			85	7		
75	2			90	7		
80	1			95	8		
85	4			100	6		

Control Class				Experimental Class			
Score	**f**	**Mean**	**SD**	**Score**	**f**	**Mean**	**SD**
90	5						
95	1						
100	2						
Total	35			Total	35		

Hypothesis Testing: Mann–Whitney U Test

Because preliminary diagnostic evaluations indicated that the dataset violated the assumption of bivariate normality required for parametric testing, a non-parametric Mann–Whitney U test was conducted to evaluate differences in posttest score rank distributions between the two instructional conditions. The inferential analysis yielded a statistically significant disparity between groups ($U = 280.50$, $p = 0.030$), successfully meeting the criterion for statistical significance ($\alpha = 0.05$). Consequently, the null hypothesis (H_0) was rejected in favor of the alternative hypothesis (H_1), confirming that the implementation of the pedagogical intervention exerted a statistically meaningful effect on students' posttest learning achievements.

A descriptive analysis of the rank ordering further elucidates the directional superiority of the integrated instructional strategy over conventional teaching practices. The experimental cohort exposed to the Discovery Learning model integrated with the Deep Learning approach (DL–DeL) achieved a mean rank of 42.67, markedly outperforming the control cohort, which registered a mean rank of 28.33. This substantial discrepancy in rank distribution substantiates the efficacy of combining structured inquiry with deep cognitive engagement, demonstrating that the DL–DeL framework provides a measurably superior learning trajectory for mastering complex ecological concepts compared to traditional direct instruction.

Table 3. Mann–Whitney U Test Results for Posttest Score Comparison Between Groups

Group	N	Mean Rank	Sum of Ranks	Mann–Whitney U	Z	p-value (2-tailed)	Decision
Experimental	35	42.67	1493.50	280.50	-2.17	30	H0 Rejected
Control	35	28.33	991.50				

Learning Gain: N-Gain Analysis

An evaluation of instructional effectiveness using the normalized gain (N-Gain) index revealed a marked disparity in learning progression between the two study conditions. The experimental cohort, which engaged with the integrated Discovery Learning–Deep Learning (DL–DeL) model, achieved a mean N-Gain score of 0.78, placing its cognitive enhancement within the "high" effectiveness tier. In contrast, the control group under conventional Direct Instruction recorded a lower mean N-Gain score of 0.66, corresponding to a "moderate" classification. This substantial divergence demonstrates that the DL–DeL intervention yielded a demonstrably superior proportional improvement in student academic growth relative to their maximum potential gain.

These quantitative findings underscore the pedagogical utility of integrating structured inquiry with deep cognitive processing. By requiring learners to actively construct conceptual frameworks while synthesizing higher-order ecological principles, the DL–DeL model effectively mitigated knowledge deficits and accelerated learning trajectories far more efficiently than traditional teacher-centred approaches. Consequently, the N-Gain analysis provides robust empirical support for the integrated model as a highly potent instructional strategy for maximizing student mastery over complex biological concepts.

Table 4. Summary of Descriptive Statistics, Inferential Test Results, and N-Gain by Group

Parameter	Experimental Class	Control Class	U Statistic	p-value
Pretest Mean (SD)	40.86 (18.04)	44.57 (19.30)	—	—
Posttest Mean (SD)	89.57 (7.51)	82.14 (10.79)	—	—
Mean Rank (Posttest)	42.67	28.33	280.5	0.03
N-Gain Score	0.78 (High)	0.66 (Moderate)	—	—

Discussion

The findings of this study provide robust empirical support for the efficacy of integrating the *Discovery Learning* model with the *Deep Learning* approach in fostering superior cognitive learning outcomes relative to conventional Direct Instruction. The significant intergroup difference in posttest scores ($p = 0.03$), combined with a high N-Gain value in the experimental class (0.78), indicates not only that students achieved higher absolute performance but that they also demonstrated markedly greater proportional knowledge construction throughout the instructional period.

The initial equivalence of both groups on the pretest (mean difference < 4 points) confirms that observed post-intervention differences are attributable to the instructional treatment rather than pre-existing ability disparities. Both groups entered the study with limited mastery of the Environmental Change and Conservation topic, as evidenced by pretest score distributions concentrated in the low-to-moderate range. This contextualises the learning gains achieved in both conditions and strengthens the inferential validity of the experimental comparison.

The superior outcomes in the experimental class are theoretically consistent with constructivist principles underlying discovery learning. By engaging students in systematic phases of stimulation, inquiry, data collection, analysis, and generalization, the DL model positioned learners as active knowledge constructors rather than passive information recipients. This active engagement has been shown to deepen conceptual understanding and improve retention, as students develop meaningful cognitive schemas through experiential processing (Faturrachim & Muanifah, 2025; Putrayasa et al., 2014; Widiadnyani et al., 2025). The present findings align with those of Mansur and Bare (2019), who demonstrated that DL applied to environmental topics yielded improved conceptual mastery through empirical experience and authentic problem-solving, and with those of Uri et al. (2024), who confirmed significant learning outcome improvements from DL on environmental change material in senior high school.

The integration of the deep learning approach amplified these constructivist benefits by directing students to connect biological content to authentic environmental phenomena in their local context (Nurwidodo et al., 2026). This contextualization is particularly significant for the topic of Environmental Change and Conservation, which encompasses complex, real-world issues—such as pollution, habitat degradation, and biodiversity loss—that cannot be effectively understood through declarative recall alone. By anchoring learning in lived environmental realities, the DeL approach facilitated meaningful learning by Ausubel, enabling students to assimilate new information within pre-existing ecological knowledge frameworks (Andayanie et al., 2025). This finding echoes Agustin's (2026) observation that DeL promotes depth of understanding by shifting instructional focus from memorization to conceptual analysis; Ferinda et al.'s (2026) conclusion that DeL enhances outcomes through meaningful, problem-connected instruction; and Nuraida and Mulyanti's (2026) report of improved conceptual understanding in DeL-based classrooms.

From a pedagogical standpoint, the DL–DeL integration appears to produce synergistic effects that neither model alone would likely achieve. DL provides the structural scaffolding for inquiry (systematic phases of discovery), while DeL provides the epistemological orientation (meaningful, contextualized, critical engagement). Together, they address both the process and the depth dimensions of learning, creating conditions conducive to higher-order thinking skill development at levels C4–C6. This is particularly relevant given that the assessment instrument was calculated to these cognitive levels, suggesting that the intervention specifically enhanced the analytical and evaluative capacities targeted by the curriculum.

The present study also contributes to understanding the applicability of the DL–DeL framework within the Indonesian secondary education context, where curriculum reform documents increasingly emphasize student-centered, project-based, and critical thinking-oriented instruction (Azzahra et al., 2023). The statistically significant and educationally meaningful gains observed in this study suggest that the DL–DeL model merits broader pedagogical adoption, particularly for conceptually complex and socially relevant biology topics.

Several limitations should be acknowledged when interpreting these findings. First, the use of purposive sampling and intact classroom groups, inherent to the quasi-experimental design, limits the generalisability of results beyond the study context. Second, the sample was drawn from a single school in Deli Serdang Regency, Indonesia, which may not be representative of broader student populations with different socioeconomic, cultural, or infrastructural characteristics. Third, the study focused exclusively on cognitive outcomes; affective and psychomotor dimensions of learning were not assessed. Future studies should incorporate longitudinal follow-up measures to assess knowledge retention, expand to multi-site samples, and include mixed-method components to explore students' metacognitive processes during DL–DeL instruction.

4. CONCLUSION

This study demonstrates that the Discovery Learning (DL) model integrated with the Deep Learning (DeL) approach is significantly more effective than Direct Instruction in improving student learning outcomes on the topic of Environmental Change and Conservation at the senior high school level. The experimental class achieved a substantially higher posttest mean (89.57 vs. 82.14), a statistically significant Mann–Whitney U test result ($p = 0.03$), a higher mean rank (42.67 vs. 28.33), and a high-category N-Gain score (0.78 vs. 0.66 moderate), collectively providing convergent evidence for the intervention's efficacy. The pedagogical mechanism underlying these outcomes involves the complementary contributions of DL's structured inquiry framework and DeL's emphasis on contextualised, meaningful engagement with authentic environmental problems. This integration cultivates not only content mastery but also higher-order thinking skills, making it well-aligned with 21st-century learning objectives and the analytical demands embedded in current Indonesian biology curricula.

These findings carry practical implications for biology teachers seeking to enhance conceptual understanding on ecology-related topics: adopting the DL–DeL model offers a theoretically grounded and empirically validated approach to instruction. Future research should extend this work to diverse school contexts, longer instructional durations, and broader arrays of outcome measures, including affective engagement and environmental literacy.

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