International Journal of Education and Teaching Zone
Volume 5, Issue 2, 2026, pp. 458-475

https://doi.org/10.57092/ijetz.v5i2.795
IJETZ
p-ISSN: 2963-7899 | e-ISSN: 2830-7925

Original Article

Biology Teachers' Awareness of the Concepts and Applications of Deep Learning in Senior High Schools

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Abstract: is study examines senior high school biology teachers' understanding of deep learning and the extent to which its principles are reflected in classroom planning and practice. An exploratory descriptive mixed-methods design was used with 20 biology teachers from public and private schools in Sleman Regency, Indonesia. Data were collected through a questionnaire on conceptual, practical, and reflective understanding, semi-structured interviews, written reflections, and document analysis of lesson plans, student worksheets, and related teaching materials. Quantitative data were analyzed descriptively, while qualitative data were analyzed through reflexive thematic analysis and rubric-based document review. Findings show that 15% of teachers were in the low category, 45% in the moderate category, and 40% in the high category. Teachers generally associated deep learning with active learning, inquiry, higher-order thinking, and project-based activities. However, documentary evidence showed that transfer-oriented tasks, explicit student agency, and authentic assessment were less consistently planned than contextual tasks and higher-order questioning. Time pressure, assessment workload, student heterogeneity, and limited institutional support were major constraints. The results suggest that teachers' readiness is promising but uneven, and that professional development should emphasize outcome-task-assessment alignment, transfer-oriented learning, and feasible authentic assessment in biology instruction

Keywords: Awareness, Biology teacher, Conceptual understanding, Deep learning

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Article History:
Received 25 March 2026; Revised 4 April 2026; Accepted 8 June 2026
Available online 30 June 2026

INTRODUCTION

Twenty-first-century education expects students not only to remember information but also to interpret evidence (Almujaddid *et al.*, 2025; Hamdani *et al.*, 2024; Pamungkas *et al.*, 2025), solve unfamiliar problems, communicate reasoning (Aschauer *et al.*, 2022; Bentz *et al.*, 2025; Coufal, 2022; English & Lehmann, 2024; Rosenlund *et al.*, 2020), and transfer knowledge to new situations (Schmid *et al.*, 2024). These expectations are especially relevant in science learning, where students are required to connect abstract concepts with real phenomena and socio-scientific issues (Çıngıl Bariş, 2024; Fang *et al.*, 2025). In biology, for example, learners are asked to explain mechanisms, interpret data, and apply scientific understanding to issues such as health, biodiversity, ecosystems, and environmental change (Atchia, 2023; Atchia *et al.*, 2024; Awaludin *et al.*, 2024; Marlina *et al.*, 2025; Pamungkas *et al.*, 2023). As a result, instructional quality is no longer judged merely by how much material is covered, but also by how far learning enables students to construct meaning, reason with concepts, and use knowledge in authentic contexts. A deep learning orientation is therefore important because it shifts attention from short-term recall to durable understanding, conceptual integration, and purposeful application (Dolmans *et al.*, 2016; Hattie & Donoghue, 2016).

In educational discourse, deep learning refers to an approach in which learners actively engage with ideas, connect prior and new knowledge, question assumptions, and generate understanding that can be applied beyond the original lesson (Ayanwale *et al.*, 2025; Bråten & Skeie, 2020; English & Lehmann, 2024). The concept is rooted in constructivist views that position learners as active meaning makers who build conceptual structures through interaction with objects, tasks, and social mediation (Piaget, 1954; Vygotsky, 1978). Contemporary learning environments also require learners to navigate knowledge networks, digital resources, and collaborative meaning-making (Akram *et al.*, 2022; Ayanwale *et al.*, 2025; Bećirović, 2023; Blau *et al.*, 2020), which is consistent with connectivism assumptions about learning in changing information ecologies (Siemens, 2005). From this perspective, deep learning is not merely "difficult" learning; rather, it is learning that demands cognitive effort being relational and reflective in nature and is applied within more innovative contexts.

Recent discussions in Indonesia frame deep learning through the intertwined principles of mindful, meaningful, and joyful learning. This framing emphasizes that learning should involve awareness, purpose, and emotional engagement rather than mechanical completion of classroom tasks. Official discourse from the Ministry of Primary and Secondary Education has linked deep learning to the strengthening of teacher competence and to the improvement of curriculum implementation in schools (Ministry of Primary and Secondary Education of the Republic of Indonesia, 2025a, 2025b). Recent literature reviews also describe deep learning as a pedagogical orientation that encourages conceptual depth, critical engagement, contextual application, and stronger learner participation (Blau *et al.*, 2020; Chirinda *et al.*, 2025; DeCoito, 2024).This state aligns with Indonesian deep learning literature that emphasizes coherent meaning-making and intentional learning experience design as core features of mindful, meaningful, and joyful learning (Akmal *et al.*, 2025; Nafi'ah & Faruq, 2025). Deep learning is best understood as a design logic for teaching and assessment, not merely as a label for active classroom activities.

Biology is a main lesson subject for deep learning because many of its core ideas are hierarchical, interconnected, and strongly related to everyday life. Understanding photosynthesis, genetics, body systems, ecology, or evolution requires more than memorizing isolated terms; students need to interpret relationships among structures, processes, and evidence. Meaningful biology learning also asks students to connect microscopic and macroscopic levels, reason about cause and effect, and use models or investigations to explain change over time. When biology is taught through disconnected facts, students may remember vocabulary temporarily but struggle to apply concepts to practical situations or to explain novel phenomena. For that reason, biology education benefits from tasks that require inquiry, project work, scientific explanation, interpretation of data, and authentic assessment of reasoning and application (Hindun *et al.*, 2024; Tarigan & Tarigan, 2022).

A deep learning orientation is often associated with student-centered pedagogies such as project-based learning (PjBL), inquiry, case-based learning, and contextual problem solving (Blundell, 2024; Chang & Yen, 2023; Mumpuni *et al.*, 2025; Suwono *et al.*, 2023). These approaches can create opportunities for students to explore authentic questions, collaborate, produce artifacts, and reflect on learning processes (Kundariati *et al.*, 2025; Kundariati & Putra, 2025; Miller & Krajcik, 2019). However, the existence of an active method alone does not guarantee deep learning outcomes. Studies on PjBL consistently show that the quality of outcomes depends on the coherence between intended learning outcomes, learning activities, scaffolding, and assessment criteria (Guo *et al.*, 2020; Krajcik & Shin, 2022; Thomas, 2000). In other words, a project or discussion becomes educationally powerful only when it is intentionally designed to promote conceptual understanding, transfer, reflection, and evidence-based assessment (Ayanwale *et al.*, 2025; Chang & Yen, 2023; Suiirbay, 2026).

Teacher understanding is central to this process (Akram *et al.*, 2022; McLure *et al.*, 2024) teachers are the main actors who interpret policy, select instructional strategies, frame learning goals, design classroom tasks, and decide what counts as acceptable evidence of learning. When teachers hold a rich understanding of deep learning, they are more likely to design tasks that go beyond procedural completion toward explanation, transfer, and authentic performance (Bai *et al.*, 2024; Dong *et al.*, 2020; Kim *et al.*, 2021). Conversely, if deep learning is understood only as "students being active" or "using HOTS questions," classroom enactment may remain partial. Teachers may adopt project labels or inquiry routines without articulating why particular tasks matter, how they support transfer, or how students' learning will be documented through authentic evidence. This makes teacher readiness a decisive factor in the success of deep learning implementation.

The challenge is intensified by practical conditions in schools. Research on teacher professional development shows that pedagogical change requires more than one-off exposure to new concepts; it depends on sustained learning opportunities, collaboration, feedback, and supportive school conditions (Sims *et al.*, 2025). In addition, teachers frequently work under time pressure, assessment demands, and heterogeneous student readiness. These constraints may lead teachers to simplify tasks, reduce student choice, or rely on conventional tests even when they conceptually support deep learning. Authentic assessment is especially demanding because it requires relevant performance tasks, explicit criteria, and feasible mechanisms for feedback and scoring (Papanastasiou *et al.*, 2025;

Vlachopoulos & Makri, 2024). For many teachers, this is the most difficult aspect of the implementation process in the classroom.

Despite the growing policy emphasis on deep learning in Indonesia, empirical evidence on teachers' readiness to enact it in subject-specific contexts remains limited. Much discussion still focuses on conceptual advocacy or broad implementation narratives, while fewer studies examine how teachers actually understand the concept, how they translate it into biology lesson planning, and where the main gaps appear between stated beliefs and documentary evidence. This gap is important because biology teachers face distinctive instructional demands, including laboratory activities, field-based inquiry, abstract conceptual content, and the need to assess both knowledge and scientific practices. A closer analysis of teachers' conceptual, practical, and reflective understanding can therefore offer a more grounded picture of readiness than policy discourse alone.\

Based on this rationale, the present study explores senior high school biology teachers' understanding and application of deep learning in Sleman Regency, Indonesia. The study addresses three related concerns: first, the level of teachers' conceptual, practical, and reflective understanding of deep learning; second, the ways deep learning principles are represented in instructional documents and described in teachers' accounts of practice; and third, the conditions, barriers, and adaptive strategies associated with implementation. By combining questionnaire data, interviews, written reflections, and document analysis, this study aims to provide an evidence-based profile of teachers' readiness and enactment. The findings are expected to contribute to the design of professional development, subject-specific guidance, and school-level support for implementing deep learning in biology instruction.

METHOD

This study employed a mixed-methods approach with an exploratory descriptive orientation. The design was selected because the study aimed not only to obtain a numerical profile of teachers' deep learning understanding, but also to examine how that understanding was interpreted, enacted, and constrained in practice. Quantitative data were used to map overall levels of understanding, while qualitative data were used to explain patterns, identify recurrent meanings, and compare teachers' self-reports with documentary evidence. The study followed an integration-at-interpretation logic, in which quantitative and qualitative strands were analyzed separately and then brought together through triangulation and joint display interpretation (Haynes-Brown & Fetters, 2021; Nabila *et al.*, 2025; Poth, 2023). This design was considered appropriate for capturing the complexity of a pedagogical construct that includes conceptual knowledge, practical enactment, and reflection.

The study was conducted in Sleman Regency, Special Region of Yogyakarta, Indonesia, in both public and private senior high schools. Data collection and analysis were carried out over a six-month period that included instrument preparation, expert validation, recruitment of participants, administration of the questionnaire, interviews, collection of instructional documents, coding of qualitative materials, and mixed-methods integration.

Sleman was chosen because it represents an active educational area with a relatively diverse school context and a continuing emphasis on curriculum implementation and teacher collaboration.

The focus on biology teachers was based on the subject's strong potential for contextual, inquiry-based, and transfer-oriented learning. The target population comprised senior high school biology teachers working in Sleman Regency, including teachers who reported previous exposure to deep learning discourse and those who had not formally implemented the approach. Participants were selected purposively to ensure that the sample included teachers willing to provide both survey responses and qualitative evidence of practice. The inclusion criteria were as follows: (1) actively teaching biology at the senior high school level, (2) willing to complete the questionnaire, (3) willing to participate in a semi-structured interview, and (4) willing to share lesson plans or teaching materials for document analysis. Participation was voluntary, and informed consent was obtained from all participants. The final sample consisted of 20 biology teachers.

Teacher understanding of deep learning (DL) refers to teachers' comprehension of DL principles and their implications for biology instruction. It covers three dimensions, they are Conceptual understanding: knowledge of DL concepts, principles, and intended learning outcomes (e.g., mindful, meaningful, joyful learning). Practical understanding: ability to translate DL principles into instructional design, including project or inquiry tasks, scaffolding, and assessment planning**.** Reflective understanding: ability to evaluate learning processes, interpret evidence of student learning, and revise instruction. Deep learning in biology instruction refers to an instructional approach that emphasizes deep conceptual understanding, connections across concepts, critical thinking, and authentic application. DL is operationalized through observable indicators in instructional planning and learning artifacts, including meaningful learning goals, transfer-oriented tasks, higher-order thinking, and authentic assessment.

Four sources of data were used. First, a teacher deep learning understanding questionnaire was developed to capture conceptual, practical, and reflective understanding using five-point Likert-scale items ranging from strongly disagree to strongly agree. The questionnaire generated a descriptive profile of teachers' self-reported readiness, and overall scores were interpreted using predetermined low, moderate, and high categories. Second, semi-structured interviews were conducted to explore teachers' interpretations of deep learning, their classroom decisions, perceived benefits, enabling conditions, barriers, and adaptive strategies. Third, document analysis was carried out on lesson plans, teaching modules, student worksheets (LKPD), and related instructional materials. A rubric was used to identify evidence of meaningful understanding, transfer orientation, higher-order thinking, student agency, scaffolding, and authentic assessment, as these elements are closely associated with deeper learning and student-centered instructional approaches such as inquiry-, problem-, and project-based learning. Evidence from recent studies also highlights the importance of assessment literacy and authentic assessment in translating such approaches into classroom practice (de Jong *et al.*, 2024; Hung & Wu, 2024; Loyens *et al.*, 2023; Otto *et al.*, 2020; Zhan *et al.*, 2025).

Fourth, short written reflections were collected to capture teachers' perceived readiness and intended improvements after discussing their practice. For the questionnaire, item grouping was aligned with the three dimensions of understanding. Items in the conceptual dimension focused on teachers' grasp of the aims and characteristics of deep learning, such as conceptual integration, higher-order thinking, transfer, and meaningful learning. Items in the practical dimension focused on instructional translation, including the design of contextual tasks, scaffolding, project or inquiry activities, and assessment planning. Items in the reflective dimension focused on monitoring learning processes, interpreting student evidence, and revising instruction. This reflective dimension was included because reflective practice is important for examining teaching decisions and improving instructional quality (Philp-Clark & Grieshaber, 2024). Scores were aggregated descriptively and then interpreted using predetermined bands to provide an overall readiness profile to communicate findings in a meaningful result.

Instrument preparation followed several steps. The questionnaire, interview guide, and document analysis rubric were drafted based on the conceptual literature on deep learning, project-based learning, authentic assessment, and mixed-methods integration. The materials were then reviewed by experts to assess content relevance, clarity, and alignment with the study objectives. Revisions were made to improve wording and reduce ambiguity in overlapping constructs. The questionnaire was checked for internal consistency using Cronbach's alpha, with 0.70 adopted as the minimum acceptable criterion. For the qualitative instruments, attention was given to prompting concrete accounts of teaching practice rather than abstract or normative answers. This was intended to produce richer evidence for triangulation across self-report and documents.

Quantitative data were analyzed using descriptive statistics, including frequencies, percentages, and category distributions. Because the study focused on profiling rather than hypothesis testing, descriptive interpretation was prioritized. Qualitative data from interviews, written reflections, and documents were analyzed using reflexive thematic analysis following phases of familiarization, coding, theme generation, review, and definition (Braun & Clarke, 2021; Braun & Clarke, 2022; Byrne, 2022). Document analysis was conducted in parallel using the rubric to identify the presence and strength of deep learning indicators in instructional plans and artifacts. Themes from interviews and reflections were then compared with documentary patterns to examine consistency between what teachers said and what their instructional materials demonstrated. For document analysis, the rubric treated the presence of deep learning indicators as observable evidence rather than as assumptions about teacher intention.

A lesson plan & student's worksheet were read for explicit learning outcomes, task design, scaffolding, opportunities for student decision-making, and assessment procedures. Evidence of meaningful understanding included concept linkage, explanatory reasoning, and contextual relevance. Evidence of transfer included tasks that required application to new cases or authentic situations. Evidence of agency included options, role structures, inquiry ownership, or self-regulation prompts. Evidence of authentic assessment included performance criteria, rubrics, product evaluation, reflection, or process-based feedback.

This analytic focus was important because written planning artifacts often reveal the extent to which pedagogical ideals have been transformed into concrete design commitments.

The research was conducted through four sequential phases to ensure methodological rigor and the credibility of the findings. The preparation phase involved a comprehensive review of the literature on differentiated learning (DL) in science education, obtaining ethical and administrative approval from the relevant authorities and participating schools, and developing the research instruments, including the questionnaire, semi-structured interview protocol, and document analysis rubric. Subsequently, the instruments underwent content validation through expert review, followed by revisions based on the experts' recommendations, while the questionnaire's internal consistency was evaluated using Cronbach's alpha with a minimum acceptable coefficient of 0.70. In the data collection phase, quantitative data were gathered through questionnaire administration to participating science teachers, whereas qualitative evidence was obtained from semi-structured interviews, lesson plans, teaching materials, and teachers' written reflections. Finally, quantitative data were analyzed using descriptive statistics, while qualitative data were examined through thematic analysis and rubric-based document analysis. The findings from both strands were then integrated using methodological triangulation and joint displays to generate a comprehensive and corroborated understanding of differentiated learning implementation in science education, thereby enhancing the validity, trustworthiness, and interpretability of the study.

Data analysis techniques include: (1) descriptive statistical analysis of questionnaire data (frequency, percentage, mean, SD) with categorization into low, moderate, and high levels; (2) thematic analysis of interview transcripts and reflections using iterative coding; (3) rubric-based content analysis of instructional documents to map DL indicators.

Integration was conducted at the interpretation stage by comparing quantitative profiles with qualitative themes and document-based evidence. Joint displays were used as an analytic device to identify areas of convergence, complementarity, and discrepancy across the data sources (Guetterman *et al.*, 2020; Haynes-Brown & Fetters, 2021; McCrudden *et al.*, 2021; Skamagki *et al.*, 2024). For example, a teacher's reported commitment to deep learning was interpreted alongside the extent to which lesson plans contained transfer-oriented tasks, authentic assessment, or explicit scaffolds. To strengthen trustworthiness, the analysis relied on repeated reading of transcripts and documents, consistent use of coding labels, and comparison across sources rather than depending on a single form of evidence. The study also maintained confidentiality by reporting aggregate results and avoiding school-level identification in the presentation of findings.

RESULT AND DISCUSSION

Teachers' deep learning understanding profile

Survey (Figure 1) results show heterogeneous levels of teachers' understanding of deep learning (DL) . Table 1 presents the descriptive profile of teachers' deep learning understanding. The 20 participating teachers, 3 teachers (15%) were categorized as having low understanding, 9 teachers (45%) moderate understanding, and 8 teachers (40%) high understanding. The distribution suggests that readiness for deep learning is promising but uneven. On the one hand, the proportion of teachers in the moderate and high categories indicates that the basic discourse of deep learning has reached schools and has been interpreted as relevant to classroom practice. On the other hand, the presence of a low-understanding group shows that not all teachers have developed the same degree of conceptual clarity. This variation is important because the implementation of a new pedagogical orientation depends not only on policy exposure but also on teachers' ability to interpret and transform that discourse into instruction.

Figure 1. Teachers Answer the Questionnaire

This distribution indicates uneven readiness across teachers. It also suggests that peer-supported professional learning is feasible, because a sizeable subgroup already demonstrates strong conceptual readiness. These findings are consistent with how DL is positioned in the Indonesian context as a learning approach grounded in mindful, meaningful, and joyful learning (Feriyanto & Anjariyah, 2024; Ministry of Primary and Secondary Education of the Republic of Indonesia, 2025b; Nafi'ah & Faruq, 2025).

Table 1. Teachers' DL understanding level (n = 20)

Level	n	%
Low	3	15%
Moderate	9	45%
High	8	40%
Total	20	100%

The quantitative findings suggest that professional learning should emphasize the deepening and consolidation of teachers' understanding rather than basic awareness. With nearly half of the teachers demonstrating moderate understanding and 40% reaching a high level, professional development should prioritize subject-specific instructional design, collaborative lesson planning, and assessment alignment. This supports current perspectives in Indonesia that position deep learning as a policy-supported pedagogical orientation for improving learning outcomes rather than merely a teaching method (Akmal *et al.*, 2025; Ministry of Primary and Secondary Education of the Republic of Indonesia, 2025a, 2025b; Nafi'ah & Faruq, 2025).

Qualitative patterns across teacher conceptions and practice

As summarized in Table 2, qualitative analysis identified five recurring domains: teachers' conceptions, instructional practices, enabling conditions, barriers, and adaptive strategies. Teachers generally viewed deep learning (DL) as active learning and higher-order thinking, supported by contextual instruction and scaffolding but constrained by limited time, assessment demands, and student readiness.

Table 2. Iterative coding results of teachers' qualitative data

No.	Analytic Domain	Recurring Pattern	Representative Code	What the pattern indicates	Evidence source	Frequency
1	Teachers' conceptions	Deep Learning (DL) interpreted as "active learning / HOTS"	"student-centered", "active discussion", "higher-order questions", "problem solving", "inquiry"	DL is understood mainly as a set of engaging strategies; coherence (transfer + assessment alignment) is not always explicit	Interviews; reflections	**15**
2	Teachers' conceptions	DL linked to meaningful understanding more than transfer	"concept mastery", "connecting concepts", "real-life context", "understanding not memorizing"	Teachers emphasize conceptual depth and relevance; transfer targets are less explicit	Interviews; lesson plans (objectives)	**15**
3	Teachers' conceptions	DL equated with PjBL activity structure	"project tasks", "product output", "presentation", "collaboration"	DL is often reduced to project format; agency, reflection, and authenticity vary	Interviews; RPP/LKPD	**16**
4	Instructional decisions	Contextual tasks and higher-order questioning as main enactment	"contextual problems", "case-based prompts", "analysis questions", "group discussion"	The most visible DL features are task context and questioning strategies	RPP/LKPD; interviews	**16**
5	Instructional decisions	Scaffolding used but not always explicit in plans	"guided worksheet", "step-by-step inquiry", "teacher prompts", "examples first"	Support exists in practice; planning artifacts may not specify scaffolds systematically	Interviews; documents	**16**
6	Instructional decisions	Authentic assessment inconsistently planned	"multiple-choice tests", "scores after project", "rubric not detailed", "assessment at the end"	Assessment becomes a bottleneck; evidence of transfer is limited in documented assessment	Documents; interviews	**15**
7	Enabling conditions	Prior training and peer collaboration support adoption	"DL workshop", "MGMP discussion", "sharing lesson plans", "peer feedback"	Professional networks help translate DL concepts into practice	Interviews; reflections	**10**
8	Enabling conditions	Leadership and school culture shape feasibility	"principal support", "school program", "time allocation", "permission for projects"	Institutional support influences sustainability beyond isolated lessons	Interviews	**5**
9	Enabling conditions	Resources and schedule flexibility	"lab access", "materials", "ICT tools", "class schedule"	Adequate resources and time increase feasibility of DL/PjBL cycles	Interviews; documents	**5**
10	Barriers	Time constraints and curriculum coverage pressure	"limited time", "many topics", "finish syllabus", "dense schedule"	Time pressure reduces depth, iteration, and reflection; projects become simplified	Interviews; reflections	**13**
11	Barriers	Assessment load and administrative burden	"grading load", "many classes", "reporting", "documentation burden"	Feasibility concerns push teachers toward simpler assessments	Interviews	**5**
12	Barriers	Student readiness and heterogeneity	"mixed ability", "low motivation", "need guidance", "group work issues"	Teachers reduce complexity or agency when readiness gaps are large	Interviews; LKPD	**7**
13	Adaptive strategies	Simplifying projects while retaining core concepts	"mini-project", "shorter cycle", "one-lesson product", "focus on one competency"	Teachers adapt DL to constraints by narrowing scope	Interviews; documents	**14**
14	Adaptive strategies	Structured LKPD to guide inquiry	"guided LKPD", "question stems", "checkpoints", "reflection prompts"	Scaffolds help manage readiness gaps and keep inquiry productive	LKPD; interviews	**16**
15	Adaptive strategies	Participation routines for collaboration	"role assignment", "group contract", "peer evaluation", "presentation rules"	Teachers use routines to improve accountability and engagement	Interviews; documents	**14**
16	Adaptive strategies	Informal formative checks during learning	"quick questions", "exit tickets", "feedback during work", "peer review"	Monitoring exists but is often informal and not always documented	Interviews; reflections	**15**

Table 2 summarizes the iterative coding results derived from interviews, lesson plans, worksheets, teacher reflections, and other instructional documents. The analysis identified five interrelated domains: teachers' conceptions, instructional decisions, enabling conditions, barriers, and adaptive strategies. Across these domains, teachers generally conceptualized deep learning (DL) as active learning and higher-order thinking, emphasizing meaningful understanding, contextual learning, and project-based activities. Classroom implementation was characterized by contextual tasks, higher-order questioning, and scaffolding to support student learning, although explicit planning for knowledge transfer, student agency, and authentic assessment remained less consistent. The findings further indicate that professional development, peer collaboration, leadership support, and the availability of instructional resources facilitated DL implementation, whereas limited instructional time, assessment workload, curriculum coverage demands, and variations in student readiness constrained teachers' practices. Rather than rejecting DL, teachers responded to these contextual challenges by adapting its implementation through simplified projects, structured inquiry worksheets (LKPD), collaborative participation routines, and ongoing informal formative assessment. The frequency distribution also shows that instructional conceptions and classroom practices appeared more consistently across participants than institutional support factors, suggesting that teachers were more confident in adopting learner-centered instructional strategies than in establishing the systemic conditions required for comprehensive DL implementation. Overall, the qualitative findings indicate that teachers have begun to internalize the core principles of DL; however, sustained implementation will require stronger support for authentic assessment, knowledge transfer, and coherent alignment among learning objectives, instructional activities, and assessment practices.

The heatmap presents a joint display matrix that integrates three qualitative data sources (interviews, instructional documents, and teacher reflections) with the themes generated through iterative coding, mapped against five deep learning (DL) indicators: meaningful understanding, transfer, student agency, higher-order thinking skills (HOTS), and authentic assessment. Each cell displays a strength score ranging from 0 to 3, where 0 indicates no evidence, 1 weak evidence, 2 moderate evidence, and 3 strong evidence of a particular theme within a specific data source.

Overall, the highest intensity appears for HOTS and meaningful understanding, particularly in interviews and instructional documents, indicating that these dimensions were consistently reflected in teachers' conceptions and lesson planning. Contextual tasks, inquiry-based questioning, and scaffolding emerged as the most consistently represented instructional practices across data sources, demonstrating strong convergence between teachers' reported beliefs and documented classroom planning. In contrast, transfer and authentic assessment display noticeably lower intensity across most themes and sources, suggesting that although teachers recognized the importance of meaningful learning, they less frequently articulated explicit transfer goals or designed assessment practices capable of capturing students' application of knowledge in authentic contexts.

The matrix (Figure 2) further reveals substantial convergence across interviews, documents, and reflections for themes related to learner-centered instruction and higher-order thinking, strengthening the credibility of these findings through data triangulation. However, weaker convergence is evident for assessment design, student agency, and transfer-oriented outcomes, indicating inconsistencies between teachers' stated intentions and documented instructional practices. This pattern suggests that teachers have largely internalized the instructional dimensions of DL but have not yet fully integrated its assessment and transfer components into classroom planning. Collectively, the joint display provides evidence that DL implementation is strongest at the level of instructional practice, while assessment alignment and the promotion of transferable learning remain the principal areas requiring further professional support and pedagogical development.

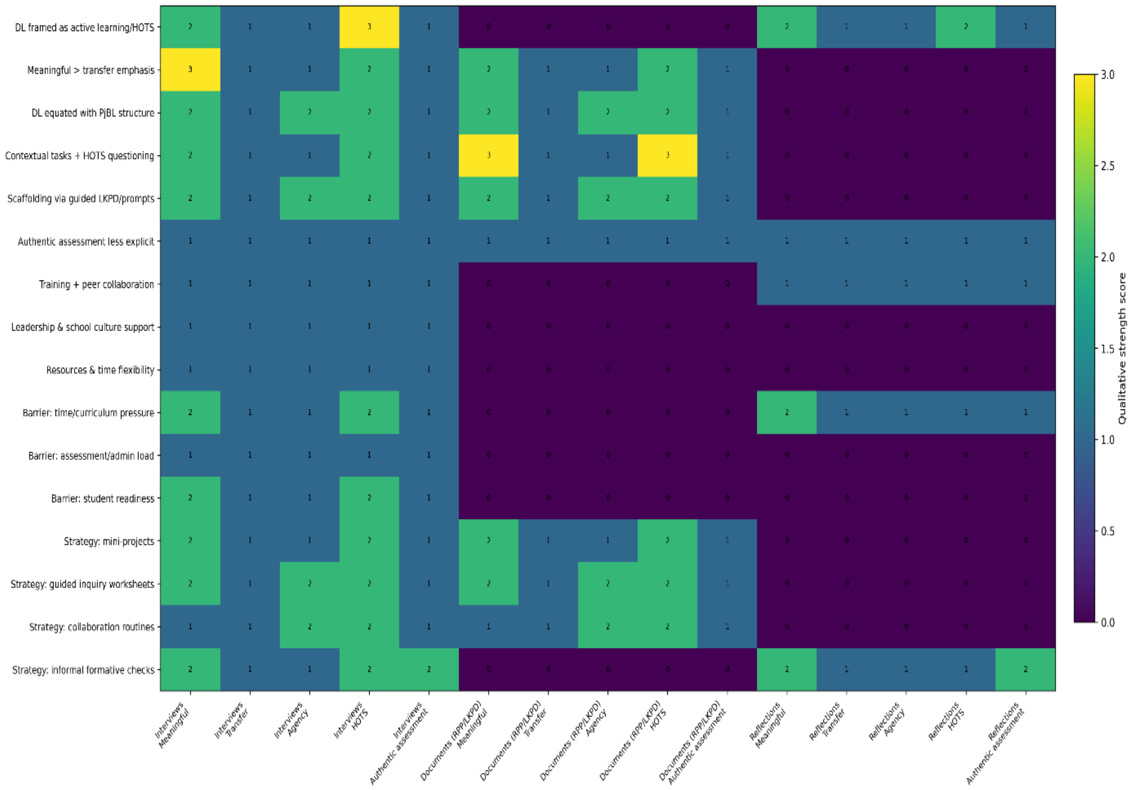

Figure 2. Heatmap of Qualitative Findings

Interview transfer refers to evidence in interview responses that teachers aim for students to apply biology knowledge and skills beyond the immediate lesson context. It includes teachers describing transfer-oriented outcomes (e.g., using concepts to interpret new phenomena, solve unfamiliar problems, or make decisions in real-life situations), designing tasks that require application in different contexts, and expecting students to generalize concepts across topics. It is coded when teachers explicitly mention "applying," "using in daily life," "solving new cases," "connecting concepts," or when they describe assignments that test application rather than recall.

Interview meaningful refers to evidence in interviews that teachers emphasize deep conceptual understanding and connected meaning-making. It includes statements about helping students understand "why/how," linking new concepts to prior knowledge, building conceptual connections across biology topics, using contexts to make concepts understandable, and prioritizing understanding over memorization. It is coded when teachers talk about conceptual clarity, reasoning, explaining mechanisms, and constructing understanding through inquiry or discussion. This interpretation is compatible with mixed-methods work that emphasizes the value of integration in explaining not just whether a pattern exists, but how different types of evidence illuminate that pattern (Guetterman *et al.*, 2020; Haynes-Brown & Fetters, 2021; Skamagki *et al.*, 2024).

Interview agency refers to evidence in interviews that teachers support student ownership and decision-making during learning. It includes descriptions of students choosing topics or approaches, generating questions, planning investigations, dividing roles, making decisions about products, monitoring their progress, and reflecting on learning choices. It is coded when teachers describe giving students options, promoting initiative, enabling autonomy in projects/inquiry, or using routines that increase student responsibility (e.g., role assignment, group contracts, self-assessment). This finding is aligned with the literature showing that authentic assessment is pedagogically desirable but operationally demanding (Papanastasiou *et al.*, 2025; Vlachopoulos & Makri, 2024).

The three analytic dimensions (conceptual, practical, and reflective) show the qualitative and documentary evidence suggests a consistent pattern. First, in the conceptual dimension, teachers commonly defined DL using familiar pedagogical frames such as active learning, inquiry, and higher-order thinking. This framing signals that DL is recognized as more than memorization. It also shows a risk of conceptual simplification, where DL is treated as a set of "engaging activities" rather than an integrated design logic that explicitly connects learning goals, learning processes, and evidence of transfer. This interpretation aligns with Indonesian DL literature that emphasizes coherent meaning-making and intentional learning experience design as core features of mindful, meaningful, joyful learning (Ambarita *et al.*, 2025; Feriyanto & Anjariyah, 2024).

Second, in the practical dimension, lesson plans and teaching materials tend to show DL elements through contextual tasks and higher-order questioning. However, these documents less consistently make transfer goals explicit, specify student agency (choice, ownership, decision points), or include authentic assessment designs aligned with intended learning outcomes. This gap is expected when teachers' understanding is moderate, because practical enactment requires design skills beyond "method selection," including alignment among outcomes, tasks, scaffolds, and assessment evidence. This pattern is also consistent with project-based learning (PjBL) studies in science education showing that stronger outcomes depend on implementation quality and careful design, not merely adopting the PjBL label (Hindun *et al.*, 2024; Tarigan *et al.*, 2025).

Third, in the reflective dimension, interview and reflection evidence suggests that teachers value evaluation and improvement, yet reflection is not always anchored in explicit evidence such as rubric-based scores, systematic analysis of student work, or documented misconceptions. Evidence-based reflection is central to DL because it supports iterative refinement of tasks, scaffolds, and assessment criteria. The limited visibility of structured reflection routines in planning artifacts can therefore explain why DL enactment appears partial even when conceptual support is present. This interpretation fits recent DL discussions that emphasize reflection, attention, and purposeful learning design as core to mindful, meaningful, and joyful learning, rather than as optional add-ons (Feriyanto & Anjariyah, 2024; Nafi'ah & Faruq, 2025).

The credibility of these interpretations is strengthened by the mixed-methods strategy and the analytic procedures used. Integration through triangulation helps compare teachers' self-reports with documentary evidence, which is recommended for producing coherent meta-inferences in mixed-methods studies (Poth, 2023). The qualitative patterns were developed using reflexive thematic analysis, which supports systematic identification of meaning patterns across interviews and reflections while remaining sensitive to context (Braun & Clarke, 2021, 2022; Byrne, 2022). Finally, the weakest points indicated by the qualitative-document patterns, and the authentic assessment are consistent with the assessment literature as presented in Figure 3.

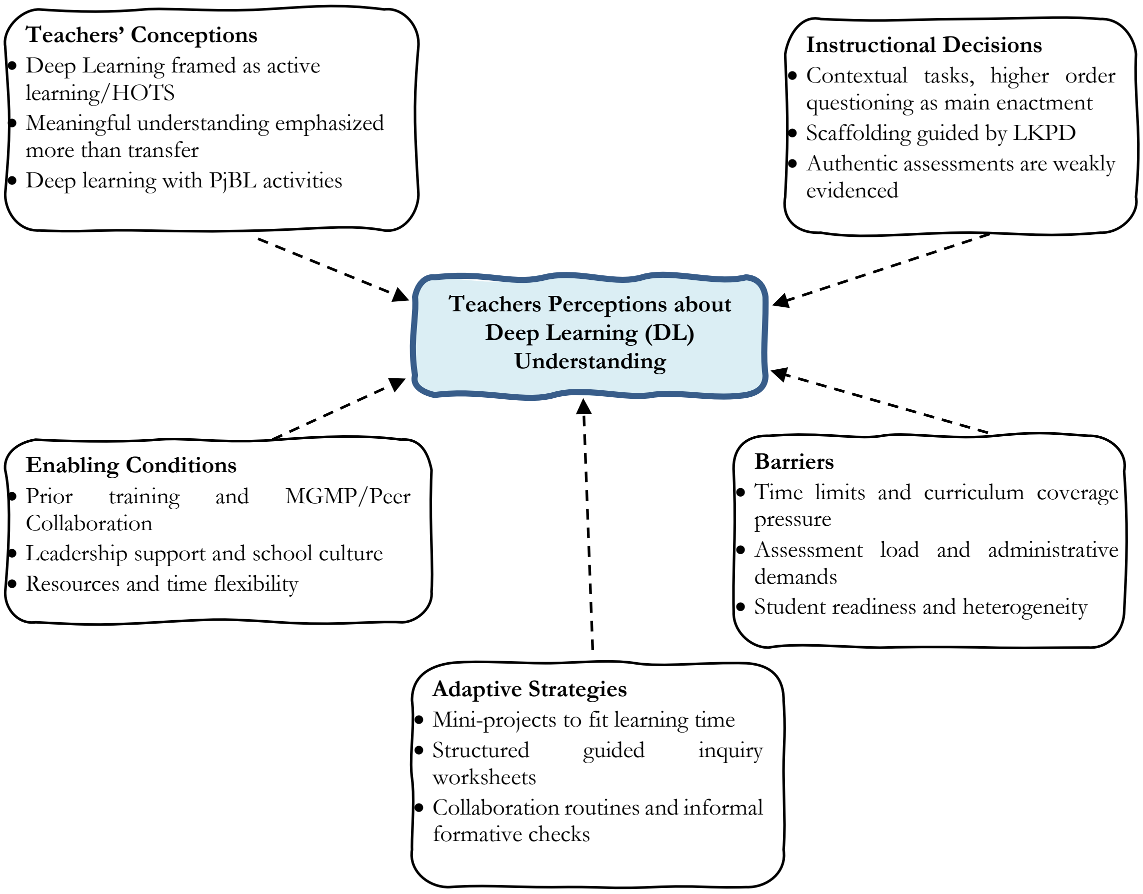

Figure 3. Domain of teachers' deep learning understanding

Recent reviews highlight that authentic assessment requires real-world tasks, clear criteria, and feasible feedback systems, which often creates a practical burden for teachers and schools (Vlachopoulos & Makri, 2024). Studies focusing on teachers' perspectives also show that willingness and perceived ability to design authentic assessment vary and are strongly shaped by training, school support, and assessment culture (Papanastasiou *et al.*, 2025). This helps explain in detail why indicators of deep learning may appear in classroom activities yet remain underdeveloped in the assessment component of lesson plans; while authentic assessment is widely regarded as having high pedagogical value, its design and implementation demand significant practical effort (Vlachopoulos & Makri, 2024; Papanastasiou *et al.*, 2025).

CONCLUSION

This study concludes that senior high school biology teachers in Sleman Regency demonstrate promising but uneven readiness to implement deep learning in biology instruction. Of the 20 participating teachers, 3 teachers (15%) were categorized as having low understanding, 9 teachers (45%) moderate understanding, and 8 teachers (40%) high understanding, showing that 85% had at least a moderate level of readiness. Qualitative findings strengthened this profile. The most frequent patterns were teachers' interpretation of deep learning as project-based activity structures (16 occurrences), their use of contextual tasks and higher-order questioning (16 occurrences), and their reliance on structured LKPD or guided inquiry scaffolds (16 occurrences). Teachers also often associated deep learning with active learning and HOTS (15 occurrences), meaningful understanding rather than memorization (15 occurrences), and informal formative checks (15 occurrences). These findings imply that deep learning implementation should move from conceptual socialization to practical, biology-specific design support. Professional development should help teachers align outcomes, tasks, scaffolding, transfer activities, and authentic assessment evidence. Schools should facilitate collaborative lesson-plan review, MGMP-based sharing of biology examples, manageable rubrics, and adequate time for inquiry, projects, and reflection. Future programs should prioritize transfer-based biology tasks, student choice and self-regulation, and clear authentic assessment instruments. Further research should involve broader samples, classroom observations, and student learning outcomes to verify whether teachers' reported understanding is consistently reflected in practice and achievement in diverse contexts.

ACKNOWLEDGMENT

The authors express their sincere appreciation to the senior high school biology teachers in Sleman Regency who voluntarily participated in this study and shared their experiences, reflections, and instructional documents. The authors also thank the participating schools for providing institutional support during the data collection process. This study was conducted in accordance with research ethics after obtaining informed consent from all participants. The authors also gratefully acknowledge the internal research funding provided by Universitas Negeri Yogyakarta.

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