

The Role of Deep Learning in Biology Education: A Metaphorical Analysis of Biology Teachers' Perspectives

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Abstract

Deep learning has become an important pedagogical approach in biology education because it promotes conceptual understanding, cognitive engagement and meaningful learning. However, biology teachers' perceptions of deep learning remain underexplored. This study investigated biology teachers' metaphorical perceptions of deep learning, identified the conceptual categories underlying these metaphors and examined differences based on gender, teaching level and teaching experience. A qualitative phenomenological design was employed involving 90 biology teachers from junior and senior high schools. Data were collected using a metaphor elicitation form in which participants completed the statement, "Deep learning in biology education is like ... because ...". The metaphors were analyzed through categorization, validation and reliability procedures, while descriptive statistics and Pearson's Chi-square tests were used to examine demographic differences. Six conceptual categories emerged: Facilitator of Understanding, Conceptual Deepener, Cognitive Learning Process, Challenging Learning Process, Teacher-Guided Learning and Meaningful Learning Outcome. The most dominant categories were Facilitator of Understanding and Conceptual Deepener, indicating that teachers primarily viewed deep learning as an approach that enhances conceptual integration and long-term understanding in biology. No significant differences were found according to gender or teaching experience, whereas teaching level significantly influenced the distribution of metaphor categories. Overall, biology teachers conceptualized deep learning as a holistic pedagogical approach that integrates cognitive engagement, teacher guidance and meaningful learning outcomes. These findings provide insights into teachers' pedagogical perspectives and offer implications for designing biology instruction that promotes deep and meaningful learning.

Keywords: Biology Teachers' Perceptions, Deep Learning, Meaningful Learning, Metaphor Analysis.

Introduction

The rapid advancement of digital technology has led to significant changes in biology teaching practices, affecting instructional strategies, learning resources and how students construct conceptual understanding (1, 2). Biology learning is inherently challenged by abstract, hierarchical and multilevel concepts, ranging from molecular processes to ecosystem interactions, which are often difficult for students to comprehend (3, 4). These challenges necessitate instructional approaches that go beyond the mere transmission of information and instead emphasize the development of deep and meaningful understanding (5, 6). Consequently, the transformation of biology education in the digital era highlights the need for pedagogical strategies that support students in integrating concepts (7, 8), reasoning about relationships among biological components (9, 10) and constructing sustainable conceptual understanding over time (11). In the context of biology education, deep learning is understood as

an instructional approach that emphasizes deep cognitive engagement, the integration of interconnected concepts and continuous reflection in the process of knowledge construction (12, 13). This approach encourages students to move beyond the memorization of biological facts toward a conceptual understanding of principles, mechanisms and the interrelationships among life processes (14). Deep learning is particularly relevant in biology education because it facilitates students' understanding of complex and systemic biological phenomena through activities involving analysis, reasoning and problem solving (15, 16). As such, deep learning serves as a pedagogical foundation that supports meaningful biology learning as well as the development of higher-order thinking skills and biological literacy (17). The successful implementation of a deep learning approach in biology education is strongly influenced by the role of biology teachers as designers, implementers and reflective practitioners of

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instruction (11). Teachers are not only responsible for delivering content but also for determining how instructional strategies are designed to promote deep conceptual understanding (18, 19). How biology teachers understand and conceptualize deep learning shapes their choices of teaching methods, learning activities and assessment practices in the classroom (20). Consequently, teachers' perceptions of deep learning become a critical factor in shaping pedagogical practices, as these perceptions can either foster or constrain meaningful learning processes (21).

Metaphors serve as cognitive tools that enable individuals to express their understanding of abstract, complex concepts that are not always easily articulated in literal terms (22, 23). In this regard, biology teachers can represent their experiences, beliefs and pedagogical orientations through more concrete and meaningful images (24, 25). Metaphor analysis was considered particularly appropriate for this study because the concept of deep learning represents an abstract pedagogical construct that is often interpreted differently by individual teachers. Unlike conventional perception surveys that primarily measure predefined attitudes or levels of agreement, metaphor analysis enables participants to express their implicit beliefs, cognitive structures and personal meanings through symbolic representations (26). Consequently, this approach provides deeper insight into how teachers conceptualize deep learning, revealing dimensions of understanding that may remain inaccessible through direct questioning alone. Previous educational studies have demonstrated that metaphor analysis is an effective methodological approach for uncovering teachers' underlying pedagogical beliefs, conceptual frameworks and professional perspectives regarding complex educational phenomena (27, 28).

Numerous studies in the field of education have employed metaphor analysis to examine teachers' perspectives on learning concepts, pedagogical approaches and instructional practices (29, 30). These studies demonstrate that metaphors are effective in revealing teachers' perceptions, beliefs and attitudes that are often not fully captured through conventional survey instruments (31). The metaphors generated by teachers reflect how they conceptualize the roles, functions and

pedagogical implications of instructional approaches in classroom practice (32, 33).

However, metaphor-based studies that specifically explore deep learning as an instructional approach in biology education, particularly from the perspective of biology teachers, remain relatively limited, thereby highlighting a clear need for further investigation within the context of biology pedagogy (34).

Based on a review of previous studies, a clear research gap can be identified regarding biology teachers' understanding of deep learning as an instructional approach (35). Therefore, there is a need for research that specifically examines the role of deep learning in biology education through metaphor analysis of biology teachers' perspectives to enrich understanding of instructional practices oriented toward deep conceptual learning (36). Although the deep learning approach has been increasingly emphasized in biology education to promote deep conceptual understanding, empirical investigations into how biology teachers interpret and position deep learning within their instructional practices remain limited. Based on these issues, the research questions of this study are as follows:

- (a) What metaphors did biology teachers generate concerning the concept of deep learning in biology education?
- (b) Under which conceptual categories do the deep learning-related metaphors generated by biology teachers fall based on their shared characteristics?
- (c) Do the metaphors generated by biology teachers regarding the concept of deep learning differ significantly according to demographic variables such as gender, teaching level and teaching experience?

Methodology

Research Design

Biology teachers' metaphorical perceptions of deep learning were investigated using a qualitative phenomenological research design. A phenomenological approach was selected because the primary objective of this study was not to develop a theory or describe a particular educational setting, but rather to understand how biology teachers experience, interpret and assign meaning to the concept of deep learning through their own perspectives. Phenomenology is particularly

appropriate when researchers seek to explore the essence of participants lived experiences and the meanings they attribute to a specific phenomenon (37). Phenomenology was considered the most appropriate approach because it enables researchers to investigate the common meanings and lived experiences shared by participants regarding a particular educational phenomenon. Since metaphors function as cognitive representations that reveal individuals' underlying beliefs, perceptions and conceptual understandings, a phenomenological framework provides an appropriate methodological foundation for exploring how biology teachers conceptualize

deep learning in biology education. Furthermore, metaphor analysis has been widely employed within qualitative phenomenological research because metaphors enable participants to express complex educational concepts that are often difficult to articulate through direct descriptions (32). By integrating phenomenology with metaphor analysis, this study sought to uncover the underlying cognitive and pedagogical structures that shape biology teachers' perceptions of deep learning, thereby providing a richer understanding than could be obtained through conventional survey-based approaches.

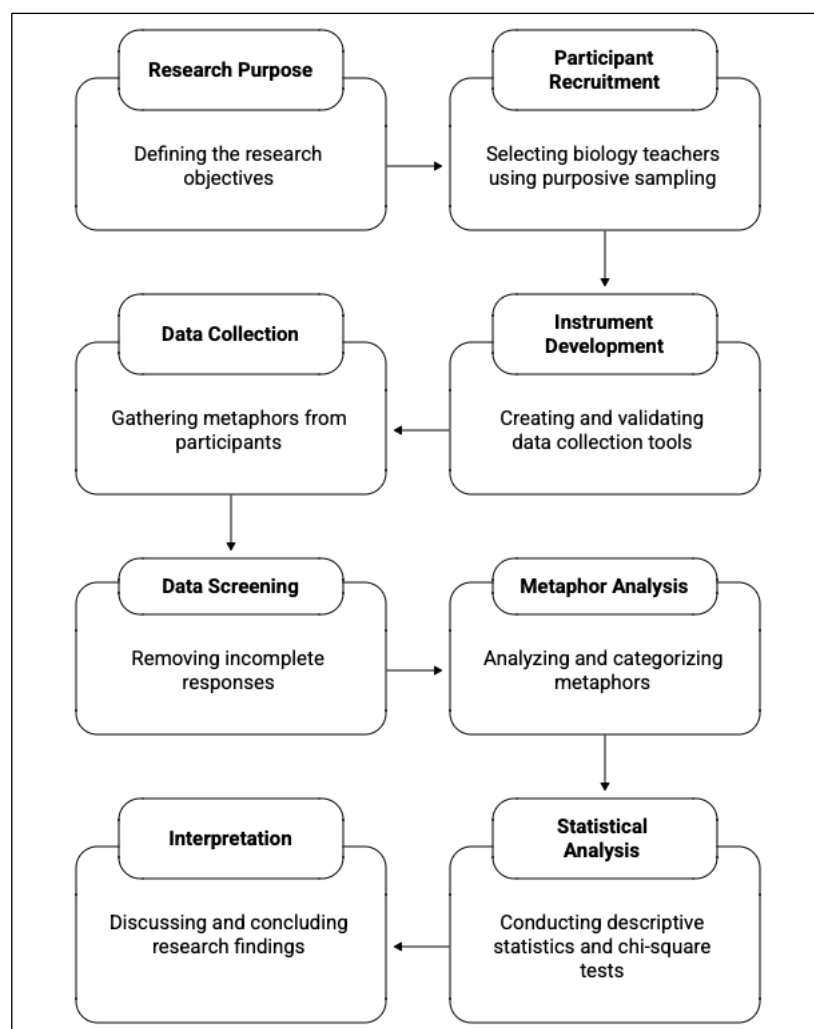


Figure 1: Research Design and Analytical Workflow of the Study

The phenomenological approach aligns closely with metaphor analysis because both seek to uncover participants' underlying cognitive structures, beliefs and interpretations. Rather than measuring predefined perceptions, metaphor analysis allows participants to communicate abstract educational concepts through symbolic

language, thereby revealing deeper conceptual understandings that might not emerge through direct questioning alone (38, 39). The use of metaphor analysis was aligned with the phenomenological design because both approaches seek to uncover the meanings individuals assign to their lived experiences. In educational

research, metaphors function as cognitive and linguistic representations that reveal how individuals organize, interpret and communicate complex concepts. Since the primary objective of this study was to explore biology teachers' conceptualizations of deep learning rather than to quantify their attitudes, metaphor analysis provided an appropriate analytical framework for identifying underlying conceptual categories and shared patterns of meaning (32). The overall research workflow is presented in Figure 1 to provide a clear representation of the methodological procedures employed in this study. The workflow illustrates the sequential stages of participant recruitment, instrument development, expert validation, pilot testing, data collection, data screening, metaphor analysis, statistical analysis and interpretation of the findings. This representation enhances the transparency and reproducibility of the research process.

Participants

The participants in this study consisted of biology teachers teaching at the junior and senior secondary school levels in public schools during the academic year in which the research was conducted. A purposive sampling strategy was employed because this phenomenological study sought participants who possessed direct experience with the phenomenon under investigation, namely, biology teaching and the implementation of deep learning in educational practice. Purposive sampling is widely recommended in qualitative phenomenological research because it enables researchers to intentionally select information-rich participants who can provide in-depth insights into the phenomenon being studied (37). Participants were recruited voluntarily through professional biology teacher networks and communication with

schools. To be eligible for participation, teachers were required to

- (a) actively teach biology at the junior or senior secondary school level,
- (b) possess an educational background in biology or biology education,
- (c) have classroom teaching experience and
- (d) provide informed consent prior to participation.

Following data collection, each response was carefully screened before analysis. Responses were retained only when participants generated a complete metaphor accompanied by a clear explanation that logically described the relationship between the metaphor and the concept of deep learning. Responses containing incomplete statements, literal descriptions without metaphorical meaning, or unclear justifications were excluded from further analysis following the procedures recommended in metaphor analysis research (32). As a result, 90 valid metaphor responses were included in the final analysis. This screening process enhanced the credibility and analytical rigor of the qualitative findings.

All participants had experience teaching biology and had been involved in the application of various instructional approaches in the classroom, including approaches oriented toward deep learning. Before data collection, participants were informed about the objectives and procedures of the study and were asked to complete an informed consent form as an indication of their voluntary participation. Several biology teachers participated in the study; however, only data from participants who produced clear and analyzable metaphors were included in the subsequent analysis. The demographic characteristics of the participants whose metaphors were deemed valid for analysis are presented in Table 1.

Table 1: Demographic Characteristics of the Participants

Characteristics	Category	Frequency (f)	Percentage (%)
Gender	Male	54	60.0
	Female	36	40.0
Teaching level	Junior High School	38	42.2
	Senior High School	52	57.8
Teaching Experience	1-5 years	21	23.3
	6-10 years	19	21.1
	10-15 years	31	34.4
	>15 years	19	21.1
Total		90	100

Table 1 presents the demographic characteristics of the participants in this study. A total of 90 biology teachers participated, consisting of 54 female teachers (60.0%) and 36 male teachers (40.0%). In terms of teaching level, the majority of participants taught at the senior high school level, with 52 teachers (57.8%), while 38 teachers (42.2%) were teaching at the junior high school level. Regarding teaching experience, the largest proportion of participants had 11–15 years of teaching experience (31 teachers; 34.4%). Teachers with 1–5 years of experience accounted for 21 participants (23.3%), whereas those with 6–10 years and more than 15 years of teaching experience each comprised 19 participants (21.1%). Overall, the distribution of participants' characteristics reflects sufficient diversity in teaching levels and professional experience to examine biology teachers' metaphorical perceptions of deep learning in biology education.

Data Collection

Data for this study were collected using a metaphor elicitation form developed by the researchers with reference to previous studies on metaphor analysis in education (40). The data collection instrument consisted of two sections. The first section aimed to gather participants' demographic information, including gender, teaching level and teaching experience. The second section was designed to elicit biology teachers' metaphors related to the concept of deep learning through an open-ended prompt: "Deep learning in biology education is like ... because ...". The use of the word "like" was intended to elicit metaphors based on participants' perceptions, while the word "because" was used to reveal the underlying reasons or meanings associated with the metaphors.

The metaphor elicitation form was developed by the researchers based on the metaphor generation procedures (40) and relevant literature on metaphor analysis in educational research. To establish content validity, the preliminary version of the instrument was independently reviewed by two experts in biology education and one expert in qualitative educational research, who evaluated the clarity of the instructions, the appropriateness of the metaphor prompt and its alignment with the research objectives. Based on their recommendations, minor revisions were made to improve the wording of the instructions

and to ensure that participants clearly understood how to construct meaningful metaphors.

Before the main study, the revised instrument was pilot-tested with 13 biology teachers who met the same inclusion criteria as the target participants but were not included in the final sample. The pilot study aimed to evaluate the clarity of the instructions, the comprehensibility of the metaphor prompt, the appropriateness of the response format and the feasibility of the data collection procedure. Feedback from the participants indicated that the instructions were generally easy to understand and that the statement "Deep learning in biology education is like ... because ..." successfully encouraged teachers to generate meaningful metaphors accompanied by logical explanations. Several participants suggested simplifying a few instructional sentences to improve readability and these recommendations were incorporated into the final version of the instrument. The pilot testing confirmed that the instrument was suitable for use in the main study.

Before data collection, participants were provided with an explanation of the concept of metaphors and the purpose of the study. The completion of the metaphor elicitation form was conducted in written form and took approximately 15 minutes. Participants were also informed that their participation was voluntary and that the data collected would be used solely for scientific purposes. Participants' willingness to take part in the study was indicated by completing an informed consent form.

Data Analysis

The analysis process was conducted through several stages, including naming and labeling metaphors, sorting (explanation and elimination stage), categorizing metaphors into conceptual categories, calculating inter-rater reliability and descriptive quantitative analysis (40). During the sorting stage, metaphors that were irrelevant, incomplete, or lacked clear justifications were eliminated, resulting in a set of valid metaphors for further analysis. The validated metaphors were then classified into several conceptual categories based on shared meanings and common characteristics.

To ensure the reliability of the analysis, the metaphors that had been categorized were independently reclassified by an expert in biology

education according to the categories developed by the researchers. The categorizations produced by the researcher and the expert were then compared to calculate the level of inter-rater agreement. Reliability was calculated using the formula $\text{reliability} = \text{consensus} / (\text{consensus} + \text{disagreement})$. An agreement rate of 90% or higher was considered indicative of acceptable reliability. Based on this calculation, the inter-rater agreement in this study reached 95%, indicating a high level of reliability.

Recognizing that qualitative interpretation is inevitably influenced by researchers' perspectives, several strategies were implemented to minimize potential bias throughout the metaphor analysis process. First, the coding and categorization of metaphors (40). Second, the preliminary categories developed by the primary researcher were independently reviewed by an expert in biology education and any discrepancies were discussed until consensus was achieved. Third, the researchers continuously compared each metaphor with participants' accompanying explanations to ensure that the assigned categories accurately reflected the intended meanings rather than the researchers' assumptions. Finally, all analytical decisions were documented throughout the coding and categorization process to enhance transparency and maintain consistency during data interpretation.

To enhance the trustworthiness of the qualitative findings, several strategies were employed following the criteria. Credibility was strengthened through expert validation of the conceptual categories, inter-rater agreement and careful examination of participants' metaphorical explanations to ensure that each metaphor accurately represented the intended meaning. Dependability was supported by employing a systematic and transparent metaphor analysis procedure, enabling the analytical process to be consistently applied throughout the study. Confirmability was enhanced by maintaining a clear audit trail of the coding, categorization and validation procedures, ensuring that the findings were grounded in participants' responses rather than researchers' subjective interpretations. Transferability was addressed by providing detailed descriptions of the research context, participant characteristics, sampling strategy and analytical procedures, allowing readers to

determine the applicability of the findings to other educational settings (38, 41).

After the processes of identification, categorization and verification were completed, the data were coded and analyzed using the Statistical Package for the Social Sciences (SPSS) version 26.0. Descriptive analyses were conducted to obtain the frequencies and percentages of each metaphor and the resulting conceptual categories. Subsequently, the Pearson Chi-square test was employed to examine the relationships between the metaphor categories and participants' characteristics, such as gender, teaching level and teaching experience. Before conducting the Pearson Chi-square test, the underlying statistical assumptions were examined (42). The data consisted of independent observations, with each participant contributing only one response to a single conceptual category. The analysis was performed using frequency data, satisfying the requirement for categorical variables. In addition, expected cell frequencies were inspected to ensure compliance with the assumptions of the Pearson Chi-square test. The assumption that no expected cell frequency was less than one and that at least 80% of the expected cell frequencies were five or greater was satisfied. Therefore, the Pearson Chi-square test was considered appropriate for examining the relationships between participants' demographic characteristics and the metaphor categories.

Results

Table 2 presents the conceptual categories and metaphors used by biology teachers to describe the concept of deep learning in the context of biology education. Of the 90 metaphors analyzed, Facilitator of Understanding emerged as the most dominant category, comprising 17 metaphors. In this category, deep learning was perceived as a means of supporting students' conceptual understanding, as reflected in metaphors such as a bridge, a map and a lens. The second most frequent category was Conceptual Deepener with 16 metaphors, portraying deep learning as an approach that strengthens conceptual foundations through metaphors, including root, foundation and microscope.

The categories Cognitive Learning Process and Teacher-Guided Learning each accounted for 13 metaphors, indicating that biology teachers viewed deep learning as an intensive cognitive

process that simultaneously requires active guidance and facilitation by the teacher. The Challenging Learning Process category included 12 metaphors, reflecting teachers' perceptions of deep learning as a demanding approach that requires sustained effort and perseverance.

Similarly, the Meaningful Learning Outcome category, also comprising 12 metaphors, emphasized the perceived outcomes of deep learning as an integrated, lasting and meaningful understanding in biology learning contexts.

Table 2: Themes and Codes Regarding the “Deep Learning” Concept in Biology Education

Conceptual Categories	Codes (Metaphors)	f
Facilitator of Understanding	Bridge [5], map [4], lens [3], ladder [3], key [2]	17
Conceptual Deepener	Root [4], foundation [4], microscope [3], puzzle [3], ecosystem [2]	16
Cognitive Learning Process	Thinking engine [4], brain workout [4], analysis tool [3], mental gym [2]	13
Challenging Learning Process	Maze [4], steep road [3], long journey [3], heavy load [2]	12
Teacher-Guided Learning	Compass [4], guide [4], facilitator [3], coach [2]	13
Meaningful Learning Outcome	Growing tree [4], woven fabric [3], living system [3], meaningful journey [2]	12
Total		90

Note: f = Frequency.

Table 3 presents the conceptual framework derived from biology teachers' metaphorical perceptions of deep learning in biology education. The category Facilitator of Understanding accounted for the largest proportion of metaphors, with 17 responses (18.9%), indicating that deep learning was predominantly perceived as an approach that supports and bridges students' understanding of complex biological concepts. This was followed by the Conceptual Deepener category, which included 16 metaphors (17.8%), reflecting teachers' views of deep learning as a means of strengthening conceptual foundations and promoting deeper comprehension.

The categories Cognitive Learning Process and Teacher-Guided Learning each comprised 13

metaphors (14.4%), suggesting that biology teachers associated deep learning with intensive cognitive engagement while emphasizing the continued importance of teacher guidance and facilitation. Meanwhile, Challenging Learning Process and Meaningful Learning Outcome each represented 12 metaphors (13.3%), highlighting teachers' recognition of deep learning as both a demanding instructional approach and a pathway toward meaningful, integrated learning outcomes. Overall, the distribution of categories illustrates a balanced conceptual framework in which deep learning is viewed not only as a cognitive process but also as a pedagogical approach that supports understanding, requires sustained effort and leads to meaningful learning in biology education.

Table 3: Conceptual Framework for “Deep Learning” in Biology Education

Conceptual Categories	Range	f	%
Facilitator of Understanding	5	17	18.9
Conceptual Deepener	5	16	17.8
Cognitive Learning Process	4	13	14.4
Challenging Learning Process	4	12	13.3
Teacher-Guided Learning	4	13	14.4
Meaningful Learning Outcome	4	12	13.3
Total	26	90	100

Note: f = Frequency, % = Percentage.

Table 4 indicates that a total of 17 metaphors were produced by the participants regarding deep learning under the Facilitator of Understanding category. Among these metaphors, “bridge” was the most frequently used ($f = 5$), suggesting that teachers commonly perceived deep learning as an approach that connects students’ prior knowledge with new and complex biological concepts.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a bridge because it helps students connect what they already know with new biological concepts.
- (b) Deep learning is like a map because it guides students step by step through complex biology topics without making them feel lost.

Table 4: Metaphors Regarding the Category as a “Facilitator of Understanding”

Metaphors	f	%
Bridge	5	29.4
Map	4	23.5
Lens	3	17.6
Ladder	3	17.6
Key	2	11.9
Total	17	100

Note: f = Frequency, % = Percentage.

Table 5 indicates that a total of 16 metaphors were produced by the participants regarding deep learning under the Conceptual Deepener category. Among these metaphors, “root” and “foundation” were the most frequently used metaphors ($f = 4$ each), indicating that teachers commonly perceived deep learning as an approach that strengthens students’ conceptual understanding and provides a solid basis for learning biology. Other metaphors, such as “microscope” and “puzzle,” further reflect the role of deep learning in

enabling students to examine biological concepts in detail and to integrate fragmented pieces of knowledge into a coherent whole.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a root because it strengthens students’ understanding and supports long-term learning in biology.
- (b) Deep learning is like a foundation because without it, students cannot build a strong understanding of biological concepts.

Table 5: Metaphors Regarding the Category as a “Conceptual Deepener”

Metaphors	f	%
Root	4	25.0
Foundation	4	25.0
Microscope	3	18.8
Puzzle	3	18.8
Ecosystem	2	12.4
Total	16	100

Note: f = Frequency, % = Percentage.

Table 6 indicates that a total of 13 metaphors were produced by the participants regarding deep learning under the Cognitive Learning Process category. Among these metaphors, “thinking engine” and “brain workout” were the most frequently used ($f = 4$ each), suggesting that teachers perceived deep learning as an approach that actively stimulates students’ cognitive processes and mental engagement in learning biology. The metaphor “analysis tool” ($f = 3$) further reflects the view that deep learning supports students in examining and reasoning

about biological phenomena. Meanwhile, the metaphor “mental gym” ($f = 2$) emphasizes the idea that deep learning requires continuous cognitive practice and effort.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a thinking engine because it continuously activates students’ thinking processes in biology learning.
- (b) Deep learning is like a brain workout because it trains students to think deeply and critically about biological concepts.

Table 6: Metaphors Regarding the Category as a “Cognitive Learning Process”

Metaphors	f	%
Thinking engine	4	30.8
Brain workout	4	30.8
Analysis tool	3	23.0
Mental gym	2	15.4
Total	13	100

Note: f = Frequency, % = Percentage.

Table 7 indicates that a total of 12 metaphors were produced by the participants regarding deep learning under the Challenging Learning Process category. Among these metaphors, “maze” was the most frequently used ($f = 4$), suggesting that teachers perceived deep learning as a learning process that requires navigation through complex and interconnected biological concepts. The metaphors “steep road” and “long journey” were each mentioned three times ($f = 3$), reflecting the view that deep learning demands sustained effort, persistence and gradual progression in

understanding biology. Meanwhile, the metaphor “heavy load” ($f = 2$) highlights teachers’ perceptions of deep learning as a cognitively demanding process that may challenge both students and teachers.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a maze because students must carefully navigate complex biological concepts to reach understanding.
- (b) Deep learning is like a long journey because meaningful understanding in biology takes time and continuous effort.

Table 7: Metaphors Regarding the Category as a “Challenging Learning Process”

Metaphors	f	%
Maze	4	33.3
Steep road	3	25.0
Long journey	3	25.0
Heavy load	2	16.7
Total	12	100

Note: f = Frequency, % = Percentage.

Table 8 indicates that a total of 13 metaphors were produced by the participants regarding deep learning under the Teacher- Guided Learning category. Among these metaphors, “compass” and “guide” were the most frequently used ($f = 4$ each), suggesting that teachers perceived deep learning as an approach that requires clear direction and guidance from the teacher in biology learning. The metaphor “facilitator” ($f = 3$) further emphasizes the role of the teacher in supporting and mediating students’ learning processes rather than merely transmitting information. Meanwhile, the meta-

phor “coach” ($f = 2$) reflects teachers’ views of deep learning as a process in which teachers motivate, guide and scaffold students’ cognitive development.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a compass because teachers help students stay on the right learning path in biology.
- (b) Deep learning is like a guide because students still need direction to understand complex biological concepts.

Table 8: Metaphors Regarding the Category as a “Teacher-Guided Learning”

Metaphors	f	%
Compass	4	30.8
Guide	4	30.8
Facilitator	3	23.1
Coach	2	15.3
Total	13	100

Note: f = Frequency, % = Percentage.

Table 9 indicates that a total of 12 metaphors were produced by the participants regarding deep learning under the Meaningful Learning Outcome category. Among these metaphors, “growing tree” was the most frequently used ($f = 4$), suggesting that teachers perceived deep learning as a process that fosters continuous growth and long-term understanding in biology learning. The metaphors “woven fabric” and “living system” were each mentioned three times ($f = 3$), reflecting the view that deep learning results in an integrated and interconnected understanding of biological

concepts. Meanwhile, the metaphor “meaningful journey” ($f = 2$) emphasizes that deep learning is seen as a learning experience that develops gradually and leads to meaningful outcomes over time.

Below are some illustrations of the metaphors:

- (a) Deep learning is like a growing tree because students’ understanding develops gradually and becomes stronger over time.
- (b) Deep learning is like a living system because biological concepts are interconnected and meaningful when understood as a whole.

Table 9: Metaphors Regarding the Category as a “Meaningful Learning Outcome”

Metaphors	f	%
Growing tree	4	33.3
Woven fabric	3	25.0
Living system	3	25.0
Meaningful journey	2	16.7
Total	12	100

Note: f = Frequency, % = Percentage.

For the third research question, a series of Chi-square tests were conducted to examine whether demographic variables, namely gender, teaching level and teaching experience, had statistically significant effects on the distribution of the conceptual categories of deep learning-related metaphors generated by biology teachers. The comparison of metaphor categories

by gender is presented in Table 10. The results indicated a non-significant effect of gender on the distribution of metaphor categories, $\chi^2(5) = 5.27, p = .38$. This finding suggests that male and female biology teachers did not differ significantly in their metaphorical perceptions of the concept of deep learning.

Table 10: Deep Learning-related Metaphors in Terms of Gender Differences

Conceptual Categories	Female		Male		Total	
	f	%	f	%	f	%
Facilitator of Understanding	10	18.5	7	19.4	17	18.9
Conceptual Deepener	9	16.7	7	19.4	16	17.8
Cognitive Learning Process	8	14.8	5	13.9	13	14.4
Challenging Learning Process	7	13.0	5	13.9	12	13.3
Teacher-Guided Learning	11	20.4	2	5.6	13	14.4
Meaningful Learning Outcome	9	16.6	3	8.4	12	13.3
Total	54	100	36	100	90	100

Note: f = Frequency, % = Percentage.

The comparison of the deep learning-related metaphor categories generated by the participants in terms of teaching level is presented in Table 11. According to the results shown in Table 11, a statistically significant effect of teaching level was found on the distribution of the conceptual categories, $\chi^2(5) = 18.62, p = .002$. Biology teachers teaching at the senior high school level generated

a higher proportion of metaphors in the Conceptual Deepener category (19.2%) compared to those teaching at the junior high school level (15.8%). In contrast, a larger proportion of junior high school teachers produced metaphors within the Teacher-Guided Learning category (18.4%) than senior high school teachers (11.5%).

Table 11: Deep Learning-related Metaphors in terms of Teaching Level Differences

Conceptual Categories	Junior High School		Senior High School		Total	
	f	%	f	%	f	%
Facilitator of Understanding	7	18.4	10	19.2	17	18.9
Conceptual Deepener	6	15.8	10	19.2	16	17.8
Cognitive Learning Process	5	13.2	8	15.4	13	14.4
Challenging Learning Process	6	15.8	6	11.5	12	13.3
Teacher-Guided Learning	7	18.4	6	11.5	13	14.4
Meaningful Learning Outcome	7	18.4	5	9.6	12	13.3
Total	38	100	52	100	90	100

Note: f = Frequency, % = Percentage.

The comparison of the deep learning-related metaphor categories generated by the participants in terms of teaching experience is presented in Table 12. According to the results shown in Table 12, the analysis revealed a non-significant effect of teaching experience on the distribution of conceptual categories, $\chi^2(15) = 13.87$, $p = .54$. This finding indicates that differences in teaching

experience did not have a statistically significant impact on the types of metaphors produced by biology teachers regarding the concept of deep learning. In other words, teachers with varying lengths of teaching experience tended to conceptualize the role of deep learning in biology education in relatively similar ways.

Table 12: Deep Learning-related Metaphors in Terms of Teaching Experience Differences

Conceptual Categories	1-5 years		6-10 years		11-15 years		>15 years		Total	
	f	%	f	%	f	%	f	%	f	%
Facilitator of Understanding	4	19.0	4	21.1	6	19.4	3	15.8	17	18.9
Conceptual Deepener	3	14.3	3	15.8	7	22.6	3	15.8	16	17.8
Cognitive Learning Process	3	14.3	3	15.8	4	12.9	3	15.8	13	14.4
Challenging Learning Process	3	14.3	2	10.5	4	12.9	3	15.8	12	13.3
Teacher-Guided Learning	4	19.0	4	21.1	4	12.9	1	5.2	13	14.4
Meaningful Learning Outcome	4	19.0	3	15.7	6	19.3	-	-	12	13.3
Total	21	100	19	100	31	100	19			

Note: f = Frequency, % = Percentage.

Discussion

The dominance of the Facilitator of Understanding category indicates that biology teachers primarily conceptualize deep learning as an instructional approach that helps students comprehend complex biological concepts. Metaphors such as bridge, map and lens reflect teachers' views that deep learning functions to connect students' prior knowledge with new concepts, provide direction in navigating abstract content and clarify intricate biological processes. This finding is consistent with the nature of biology as a discipline that requires the integration of concepts across multiple levels of organization, from molecular mechanisms to ecosystem interactions (43, 44). Teachers emphasize the role

of deep learning in reducing conceptual fragmentation and promoting coherent understanding rather than mere factual acquisition. Thus, deep learning is not perceived as an approach that simply increases cognitive load, but rather as a pedagogical strategy that structures students' conceptual pathways in a more meaningful manner.

Beyond confirming previous studies that emphasize the role of deep learning in promoting conceptual understanding, the present findings extend the literature by highlighting how biology teachers themselves conceptualize this approach as a cognitive bridge that connects fragmented biological knowledge into coherent conceptual

structures. While earlier studies have primarily focused on the effects of deep learning on students' learning outcomes and higher-order thinking skills, this study reveals teachers' perspectives regarding its pedagogical function in facilitating conceptual progression (45). This difference may reflect teachers' professional responsibility for organizing learning experiences that help students navigate the hierarchical and interconnected nature of biological concepts (46). Consequently, the metaphorical representations identified in this study provide additional evidence that deep learning is viewed not merely as a cognitive strategy but also as an instructional mechanism for supporting meaningful conceptual integration in biology education.

The emergence of the Conceptual Deepener category as the second most dominant further indicates that biology teachers view deep learning as an approach that plays a crucial role in strengthening students' conceptual foundations. Metaphors such as root, foundation and microscope depict deep learning as a learning process that goes beyond surface-level engagement and is oriented toward deep and long-term understanding. These metaphors reflect teachers' beliefs that biological concepts must be constructed on a solid foundation to enable students to relate, analyze and meaningfully extend more advanced concepts. Given that biology learning requires causal and systemic understanding, misconceptions at the foundational level can hinder students' ability to comprehend subsequent concepts (47). In this regard, deep learning is perceived as an approach that supports the development of stable, analytical and integrated knowledge structures in biology education (48–50).

The prominence of this category also suggests that biology teachers perceive conceptual understanding as the foundation upon which higher-order cognitive processes are built. Although previous studies frequently associate deep learning with critical thinking and problem-solving abilities, the metaphors identified in the present study indicate that teachers first emphasize the importance of establishing robust conceptual structures before expecting students to engage in analytical reasoning (51). This interpretation is particularly relevant in biology education, where misconceptions at fundamental

conceptual levels may hinder subsequent learning of more advanced biological processes. Therefore, the findings contribute a pedagogical perspective that complements previous outcome-oriented research by demonstrating that teachers regard conceptual depth as a prerequisite for meaningful cognitive development.

The Cognitive Learning Process category indicates that biology teachers perceive deep learning as an approach that requires active and intensive cognitive engagement from students. Metaphors such as thinking engine and brain workout reflect the perception that deep learning encourages students to continuously process information, reason about cause–effect relationships and critically evaluate biological concepts. This view suggests that deep learning is not understood as a passive process, but rather as a sustained and intellectually demanding mental activity. Such cognitive engagement is crucial, as understanding biological concepts often requires high-level analysis, synthesis and reasoning (3). This category underscores the role of deep learning in fostering higher-order thinking skills and strengthening students' scientific reasoning processes in biology education.

Compared with previous studies, the present findings provide a broader understanding of cognitive engagement by illustrating how teachers perceive deep learning as a continuous intellectual process rather than a discrete instructional strategy. Metaphors such as thinking engine and brain workout imply that cognitive effort is viewed as an ongoing process requiring sustained reflection, reasoning and conceptual refinement (33). This perspective reinforces constructivist views of learning, which emphasize that meaningful understanding develops gradually through active knowledge construction rather than passive information acquisition (52). Accordingly, biology teachers appear to recognize that deep learning involves sustained cognitive engagement that extends beyond classroom activities and supports long-term conceptual development.

The Challenging Learning Process category reflects biology teachers' awareness of the complexity and cognitive demands inherent in the implementation of deep learning. Metaphors such as maze, steep road and long journey suggest that deep learning is perceived as a non-instantaneous

process that requires sustained effort, perseverance and careful conceptual navigation. This perspective indicates that teachers recognize the challenges students face in developing deep understanding of abstract and interconnected biological concepts (53, 54). These challenges are not viewed as obstacles, but rather as integral components of meaningful learning. Accordingly, deep learning is understood as an approach that requires both cognitive and pedagogical readiness (55, 56), from both students and teachers to achieve higher levels of conceptual understanding in biology education.

Interestingly, the metaphors categorized within this theme portray challenge as a productive component of learning rather than as an obstacle to be avoided. Unlike studies that describe learning difficulties primarily as barriers to academic achievement, the present findings suggest that biology teachers perceive cognitive struggle as an essential element of meaningful conceptual development (57). This interpretation may be attributed to the inherently complex nature of biological knowledge, which requires students to integrate multiple levels of organization and causal relationships (58). The identified metaphors indicate that teachers recognize productive cognitive challenge as an important characteristic of deep learning that ultimately contributes to more durable conceptual understanding.

The Teacher-Guided Learning category emphasizes that biology teachers perceive deep learning as an instructional approach that continues to require the active role of teachers as guides and facilitators of the learning process. Metaphors such as compass, guide and coach reflect the belief that although deep learning promotes student autonomy and cognitive engagement, successful learning is highly dependent on the scaffolding provided by teachers. In biology education, the teacher's role is crucial in helping students navigate complex concepts, avoid misconceptions and connect theoretical knowledge with relevant biological phenomena. These findings indicate that deep learning is not understood as a purely student-centered approach devoid of guidance, but rather as a collaborative process (17, 21) in which teachers act as conceptual mediators to ensure that learning remains structured, meaningful and aligned with the goals of biology education (59).

This finding also provides an interesting contrast to contemporary perspectives that frequently emphasize learner autonomy as the defining characteristic of deep learning. While student-centered learning encourages independence, the metaphors generated in this study indicate that biology teachers continue to view teacher guidance as indispensable for supporting conceptual development (17, 59). This apparent discrepancy may be explained by the complexity of biological concepts, which often require scaffolding to help students establish accurate conceptual relationships and avoid misconceptions. Therefore, rather than viewing teacher guidance and student autonomy as opposing approaches, the findings suggest that teachers perceive them as complementary elements that jointly facilitate meaningful learning.

The Meaningful Learning Outcome category shows that biology teachers conceptualize deep learning as an approach oriented toward achieving sustainable and integrated understanding. Metaphors such as a growing tree, a living system and woven fabric illustrate the view that learning outcomes in biology are not instantaneous but develop gradually through the interconnection of mutually reinforcing concepts. This interpretation aligns with the nature of biology as a life science that emphasizes systemic relationships among processes and structures (60). By perceiving deep learning as a process that leads to meaningful learning outcomes, teachers highlight the importance of conceptual understanding that endures over time and can be transferred to new contexts. Thus, deep learning is perceived not merely as an instructional approach, but also as a means of fostering holistic, contextual and life-relevant understanding of biology among students. These findings further reinforce the theoretical perspective that meaningful learning is characterized by the integration of new knowledge with existing cognitive structures. However, the present study extends previous literature by demonstrating that biology teachers perceive meaningful learning not only as an educational outcome but also as a continuous developmental process represented through dynamic metaphors such as growing tree and living system (61). Such metaphors illustrate that teachers regard conceptual understanding as evolving over time through repeated reflection and conceptual

connections. This perspective underscores the importance of designing biology instruction that supports sustained conceptual growth rather than short-term knowledge acquisition (51, 62).

The findings of this study indicate that there were no statistically significant gender differences in biology teachers' metaphorical conceptualizations of deep learning. This suggests that female and male biology teachers share relatively similar pedagogical beliefs regarding the role of deep learning in biology instruction. One possible explanation is that contemporary teacher education and professional development programs provide comparable pedagogical preparation regardless of gender, leading teachers to develop similar understandings of student-centered learning, conceptual understanding and meaningful learning. Moreover, biology teachers generally work within the same national curriculum and professional standards, which emphasize comparable instructional goals and pedagogical competencies. Consequently, their conceptualizations of deep learning are likely to be shaped more strongly by shared professional knowledge and instructional experiences than by demographic characteristics such as gender.

These findings also suggest that teachers' perceptions of deep learning are grounded in the epistemological characteristics of biology as a discipline rather than in personal attributes. Biology requires students to understand interconnected systems, causal mechanisms and hierarchical concepts, which naturally encourage teachers to adopt similar pedagogical perspectives irrespective of gender. Therefore, the absence of significant gender differences should not be interpreted as a lack of meaningful perception but rather as evidence of a shared professional understanding of deep learning among biology teachers. This finding supports previous educational research indicating that teachers' pedagogical beliefs are more strongly influenced by professional learning experiences and disciplinary contexts than by gender differences (63).

In contrast to the gender-related findings, this study reveals that teaching level has a statistically significant influence on biology teachers' metaphorical perceptions of deep learning. Biology teachers at the senior high school level tended to conceptualize deep learning more

frequently within the Conceptual Deepener category, reflecting the greater emphasis on conceptual understanding, analysis and integration of abstract biological concepts at this level of education. Conversely, junior high school biology teachers more commonly conceptualized deep learning within the Teacher-Guided Learning category, indicating a stronger need for intensive pedagogical guidance in establishing students' foundational understanding. Differences in students' developmental characteristics and the complexity of biological content across educational levels play an important role in shaping how teachers interpret and implement deep learning (11). Thus, deep learning is not perceived uniformly across teaching levels but is instead adapted to pedagogical needs and students' cognitive developmental characteristics at each educational stage (13, 17, 21).

The present study also found that teaching experience did not significantly influence biology teachers' metaphorical conceptualizations of deep learning. This finding suggests that both novice and experienced teachers tend to construct relatively similar understandings of deep learning as a pedagogical approach. A possible explanation is that deep learning has become an important educational paradigm promoted through curriculum reforms, teacher professional development and contemporary educational discourse, enabling teachers across different career stages to develop comparable conceptual understandings. Furthermore, biology teachers frequently encounter similar instructional challenges, such as helping students understand abstract concepts, addressing misconceptions and promoting higher-order thinking skills. These common instructional demands may contribute to the convergence of teachers' pedagogical perceptions regardless of their years of teaching experience.

Another possible interpretation is that teaching experience alone does not necessarily determine teachers' conceptual understanding of innovative pedagogical approaches. Rather, continuous professional learning, participation in educational communities and engagement with curriculum development may play a more influential role in shaping teachers' perceptions of deep learning. Therefore, the absence of statistically significant differences should be interpreted as evidence that

deep learning has been recognized as a shared pedagogical orientation among biology teachers rather than as an approach limited to particular experience levels. This interpretation is consistent with studies suggesting that teachers' pedagogical beliefs are influenced by ongoing professional learning and instructional contexts rather than teaching experience alone (57).

Collectively, the findings of this study form a conceptual framework of the role of deep learning in biology education that integrates facilitation of understanding, conceptual deepening, cognitive engagement, learning challenges, teacher involvement and meaningful learning outcomes. This synthesis demonstrates that biology teachers perceive deep learning as a holistic pedagogical approach, oriented not only toward higher-order cognitive processes but also toward structured and meaningful learning experiences. The results reinforce the view that deep learning in biology education is closely associated with meaningful learning and conceptual change, in which understanding is constructed gradually, integratively and contextually. Furthermore, these findings underscore the value of metaphor analysis as an effective methodological approach for uncovering teachers' cognitive and pedagogical structures that are often not fully captured through conventional survey-based methods. Consequently, this study provides a theoretical foundation that enriches biology education research, particularly in advancing understanding of how teachers conceptualize and position deep learning within their instructional practices.

Conclusion

This study concludes that biology teachers conceptualize deep learning as an instructional approach that plays a crucial role in facilitating conceptual understanding, deepening knowledge structures and fostering intensive cognitive engagement in biology learning. Through metaphor analysis, six major conceptual categories were identified to represent how teachers position deep learning: Facilitator of Understanding, Conceptual Deepener, Cognitive Learning Process, Challenging Learning Process, Teacher-Guided Learning and Meaningful Learning Outcome. The dominance of the Facilitator of Understanding and Conceptual Deepener categories indicates that deep learning is

perceived as a pedagogical approach that supports students in coherently integrating biological concepts and developing long-term understanding. From a theoretical perspective, these findings enrich biology education research by reaffirming the relevance of deep learning in promoting meaningful learning and conceptual change, while also highlighting the contribution of metaphor analysis as an effective methodological approach for uncovering teachers' cognitive and pedagogical structures within the context of biology education. The findings of this study also provide practical implications for biology instruction and teacher professional development, particularly in designing learning experiences oriented toward deep learning. Biology teachers are encouraged to develop instructional strategies that emphasize conceptual connections, deep reasoning and continuous reflection, while providing appropriate scaffolding aligned with students' educational levels and characteristics. Furthermore, the results may inform teacher training programs by emphasizing conceptual understanding of deep learning rather than focusing solely on the application of instructional methods.

Nevertheless, this study has several limitations that should be considered when interpreting the findings. First, the use of purposive sampling, while appropriate for phenomenological research, may limit the transferability of the findings because the participants were intentionally selected based on specific inclusion criteria rather than through probability sampling. Consequently, the findings should not be generalized to all biology teachers or to teachers from other educational contexts. Second, this study was conducted within a specific educational and cultural context, where teachers operate under similar curriculum policies and professional expectations. Teachers' metaphorical conceptualizations of deep learning may therefore be influenced by local educational practices, cultural values and institutional environments, which may differ across regions or countries. Third, the findings were derived from self-reported metaphorical expressions, which reflect participants' personal perceptions at the time of data collection. Although metaphors provide rich insights into teachers' conceptual understandings, they may not necessarily represent teachers' actual classroom practices or instructional

behaviors. Finally, the interpretation and categorization of metaphors inevitably involve a degree of researcher subjectivity, despite the implementation of expert validation and high inter-rater reliability. Although several procedures were undertaken to enhance the trustworthiness of the analysis, alternative interpretations of some metaphors may still be possible. Future studies are therefore encouraged to employ multiple qualitative data sources, such as classroom observations, interviews, or focus group discussions, together with broader participant populations from different cultural and educational settings to further strengthen the transferability and credibility of the findings.

Although the findings provide valuable insights into biology teachers' metaphorical conceptualizations of deep learning, their transferability to other educational settings should be considered with caution. The participants in this study were recruited from public secondary schools within a specific educational context; therefore, the findings may not fully represent the perspectives of teachers working in private schools, rural schools, or educational systems with different curriculum structures, institutional cultures and pedagogical traditions. Variations in school resources, professional development opportunities, organizational support and educational policies may influence how teachers conceptualize and implement deep learning in practice. Consequently, future studies are encouraged to examine teachers from more diverse educational settings, including private institutions, rural and remote schools and different national educational systems, to determine the extent to which the conceptual categories identified in this study remain consistent across broader contexts.

Abbreviations

AI: Artificial Intelligence, SPSS: Statistical Package for the Social Sciences.

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Author Contributions

Mira AR: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Nurhayati B: Methodology, Validation, Formal Analysis, Writing – Review and Editing, Faisal: Investigation, Data Curation, Resources, Visualization, Andi Faridah Aarsal: Supervision, Project Administration, Validation, Writing – Review and Editing. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study. The authors also confirm that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The data are not publicly available because they contain information that could compromise participant confidentiality.

Declaration of Artificial Intelligence (AI) Assistance

During the preparation of this manuscript, the authors used Generative Artificial Intelligence (AI) tools solely to improve the clarity, grammar and readability of the English language. The authors carefully reviewed and edited all AI-assisted outputs and take full responsibility for the accuracy, originality, interpretation and integrity of the manuscript. No AI tools were used for data collection, data analysis, interpretation of findings, or generation of research results.

Ethics Approval

This study was conducted in accordance with ethical principles for research involving human participants. Prior to data collection, all participants were informed about the objectives and procedures of the study and voluntarily provided informed consent. Participants' anonymity and confidentiality were maintained throughout the research process and all data were used exclusively for research purposes.

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