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Advancing SDG 4 through Deep Learning Approaches: Reconstructing Student Learning from Metacognitive and Higher-Order Thinking Skills Perspectives

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ABSTRACT

Objective: *To reconstruct student learning within the context of sustainable quality education by exploring the integration of deep learning approaches, metacognition, and Higher-Order Thinking Skills (HOTS) in higher education. The study responds to the persistent dominance of memorization-oriented and procedural learning practices that limit students' cognitive development and lifelong learning capacities.* ***Methods***: *A qualitative conceptual design was employed using thematic analysis of scholarly literature published between 2022 and 2026. Relevant studies on deep learning, metacognition, HOTS, and sustainable higher education were systematically reviewed to identify key themes and conceptual relationships.* ***Results***: *The analysis demonstrates that deep learning promotes meaningful cognitive engagement, reflective awareness, and active knowledge construction. Metacognitive regulation functions as a central mechanism linking deep learning and HOTS through planning, monitoring, and evaluating learning processes. Furthermore, inquiry-based learning, reflective activities, and authentic problem-solving experiences enhance students' analytical reasoning, creativity, adaptability, and critical thinking, which are essential competencies for sustainable learning and future workforce readiness.* ***Novelty***: *The proposes an integrated conceptual framework that connects deep learning, metacognition, and HOTS within the broader agenda of Sustainable Development Goal 4 (Quality Education). The framework offers a comprehensive perspective for transforming student learning from surface-level knowledge acquisition to meaningful and reflective learning, while providing theoretical insights for educators and researchers seeking to promote sustainable and transformative educational practices in higher education.*

INTRODUCTION

The transformation of higher education in the twenty-first century has fundamentally changed the orientation of learning. Universities are no longer expected merely to transfer knowledge, but also to cultivate students who are capable of critical thinking, reflective reasoning, problem solving, and adaptive decision-making in complex professional contexts (Fullan et al., 2023; Huang et al., 2023). In this situation, learning outcomes are not sufficiently measured through memorization or procedural competence alone, but through students' ability to construct meaning, regulate their own thinking processes, and apply knowledge in authentic situations. Consequently, the discourse surrounding *deep learning*, metacognition, and Higher-Order Thinking Skills (HOTS) has become increasingly central in contemporary educational research.

The growing emphasis on deep learning, metacognition, and Higher-Order Thinking Skills (HOTS) is closely aligned with the global agenda of Sustainable Development Goal 4 (SDG 4), which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (UNESCO, 2024; OECD, 2023). Contemporary higher education institutions are expected not only to equip students with disciplinary knowledge but also to foster critical thinking, reflective

learning, adaptability, and problem-solving competencies required to address complex social, economic, and environmental challenges. Therefore, the reconstruction of student learning through deep learning approaches represents an important pathway toward achieving sustainable educational transformation and strengthening the quality of higher education in the twenty-first century.

Despite the growing emphasis on student-centered learning in higher education, many learning practices still reflect characteristics of surface learning (Zhao & Sullivan, 2024; Chen & Lien, 2022). Students often focus on completing assignments, reproducing information, and meeting assessment requirements rather than developing conceptual understanding and reflective thinking. In many classroom contexts, learning activities remain dominated by lecturer explanations, fragmented tasks, and assessment systems that prioritize short-term achievement over meaningful understanding. As a result, students may achieve satisfactory academic scores while demonstrating limited analytical reasoning, weak self-regulation, and low capacity for transferring knowledge into real-world contexts.

This phenomenon indicates a fundamental contradiction between the goals of modern higher education and the realities of instructional practice. Universities aspire to produce graduates who are innovative, reflective, and capable of solving multidimensional problems; however, learning environments frequently fail to support the cognitive depth required to achieve these outcomes. The persistence of passive learning cultures has contributed to the limited development of metacognitive awareness and HOTS among university students. In practice, many students are still dependent on lecturer guidance, struggle to evaluate their own learning strategies, and encounter difficulties when faced with open-ended or complex problems that require critical and creative thinking.

While the concept originated from Marton and Säljö's distinction between deep and surface learning, contemporary studies continue to demonstrate its relevance in fostering meaningful cognitive engagement and adaptive learning outcomes (Huang et al., 2023; Zhao & Sullivan, 2024). who distinguished deep approaches to learning from surface approaches. Deep learning emphasizes active meaning-making, conceptual understanding, knowledge integration, and reflective engagement with learning content. Students who engage in deep learning tend to connect ideas, question assumptions, and construct understanding beyond memorization. This perspective aligns closely with constructivist learning theory, which argues that knowledge is actively constructed through experience, reflection, and interaction rather than passively received from instructors.

Furthermore, the development of deep learning is strongly associated with metacognitive theory proposed by John Flavell (Panadero, 2023; Dinsmore & Zoellner, 2022), who conceptualized metacognition as an individual's awareness and regulation of their own cognitive processes. Metacognitive learners are capable of planning, monitoring, and evaluating their learning strategies, enabling them to become more autonomous and reflective learners. In higher education contexts, metacognitive ability is particularly important because students are expected to manage increasingly complex learning demands independently.

In addition, the framework of Higher-Order Thinking Skills (HOTS), derived from the revised taxonomy of Benjamin Bloom developed by Lorin Anderson and David Krathwohl, emphasizes cognitive processes such as analyzing, evaluating, and

creating (Kim & Cross, 2024; Sulaiman et al., 2023). HOTS represents an essential competency in contemporary education because it enables students to interpret information critically, solve authentic problems, and generate innovative ideas. Nevertheless, the cultivation of HOTS cannot occur effectively within learning environments that are predominantly procedural and teacher-centered. HOTS requires learning experiences that encourage inquiry, reflection, conceptual exploration, and cognitive challenge, all of which are fundamental characteristics of deep learning approaches.

Although numerous studies have examined deep learning, metacognition, or HOTS independently, research integrating these three constructs within a unified framework remains limited. Existing studies frequently focus on instructional models or technological interventions without comprehensively explaining how deep learning approaches reconstruct the learning process itself through metacognitive engagement and higher-order thinking development. Moreover, previous research often measures learning achievement quantitatively while paying insufficient attention to the transformation of students' cognitive awareness and reflective learning behavior. This creates a significant research gap, particularly in understanding how deep learning can function not merely as a teaching strategy, but as a paradigm for reconstructing student learning in higher education.

Despite the growing body of research on deep learning, metacognition, and HOTS, limited studies have examined these constructs within an integrated framework that explicitly contributes to sustainable quality education and SDG 4. Existing research tends to focus on instructional effectiveness, technological interventions, or isolated cognitive outcomes rather than exploring how deep learning, metacognitive regulation, and higher-order thinking collectively reconstruct student learning. As a result, there remains insufficient theoretical understanding of how these interconnected dimensions can support transformative and sustainable learning in higher education. This gap highlights the need for a comprehensive conceptual framework capable of explaining the role of deep learning in advancing educational quality and lifelong learning competencies.

Another important gap lies in the contextual application of deep learning approaches in professional and vocational higher education environments. In many practice-oriented disciplines, learning is still heavily focused on technical competence and procedural performance, while reflective thinking and metacognitive development receive less systematic attention. As a result, students may demonstrate operational skills without fully developing the analytical and adaptive capacities required in dynamic professional settings. This condition suggests the need for a more holistic learning reconstruction that integrates cognitive depth, reflective awareness, and higher-order thinking processes.

Therefore, this study proposes a conceptual reconstruction of student learning through deep learning approaches by positioning metacognition and Higher-Order Thinking Skills (HOTS) as interconnected dimensions of meaningful and sustainable learning. The novelty of this study lies in integrating deep learning theory, metacognitive regulation, and HOTS within the broader framework of SDG 4, thereby extending existing discussions beyond instructional strategies toward a transformative learning paradigm.

Accordingly, this study aims to: (1) examine the conceptual relationship between deep learning, metacognition, and HOTS in higher education; (2) identify the role of metacognitive regulation in supporting higher-order thinking development; and (3) propose an integrated conceptual framework for reconstructing student learning that contributes to sustainable quality education and lifelong learning. Through this framework, the study seeks to provide theoretical insights for educators, curriculum developers, and researchers interested in advancing SDG 4 through transformative higher education practices.

RESEARCH METHOD

This study employed a qualitative conceptual research design to examine the interrelationship among deep learning, metacognitive regulation, and Higher-Order Thinking Skills (HOTS) in higher education. The study aimed to develop a comprehensive conceptual framework for reconstructing student learning in support of Sustainable Development Goal 4 (SDG 4), which emphasizes quality education and lifelong learning opportunities. Rather than investigating causal relationships statistically, this research focused on synthesizing contemporary educational theories and empirical findings to provide a deeper understanding of how deep learning approaches contribute to meaningful and transformative learning.

A literature-based conceptual analysis framework was adopted because it enables researchers to critically interpret and integrate theoretical perspectives from different educational traditions. The study was grounded in constructivist learning theory, reflective learning theory, self-regulated learning theory, and transformative learning perspectives. Through this approach, the study explored how deep learning, metacognition, and HOTS interact within contemporary higher education contexts and contribute to sustainable educational development.

Literature sample and data sources

The data sources consisted of scholarly literature published between 2022 and 2026, including peer-reviewed international journal articles, academic books, conference proceedings, and higher education policy reports. The literature was retrieved from internationally recognized academic databases such as Scopus, Web of Science, ERIC, and Google Scholar.

The literature selection process followed purposive sampling principles based on four criteria:

1. Conceptual relevance to deep learning, metacognition, and HOTS.
2. Contribution to higher education pedagogy and sustainable learning.
3. Publication in credible academic journals or scholarly publishers.
4. Alignment with contemporary discourse on student-centered, reflective, and transformative learning.

The emphasis on recent publications ensured theoretical relevance and alignment with current educational challenges related to cognitive engagement, reflective learning, and lifelong learning competencies.

Instrument and procedures

In qualitative conceptual studies, the primary research instrument is the researcher. To support systematic analysis, a literature review matrix was developed to record

publication characteristics, theoretical perspectives, major findings, and conceptual relationships among the selected studies.

The research procedures consisted of four stages:

1. Identification of relevant literature related to deep learning, metacognition, HOTS, and sustainable education.
2. Screening and selection of literature according to the predetermined inclusion criteria.
3. Organization and classification of literature into major conceptual themes.
4. Interpretation and synthesis of findings to construct an integrated conceptual framework explaining the relationship among deep learning, metacognitive regulation, and HOTS.

This procedure enabled a systematic reconstruction of student learning from contemporary higher education perspectives.

Data analysis

Data were analyzed using thematic conceptual analysis. Following Braun and Clarke's thematic analysis framework, the analysis was conducted through several stages:

1. Familiarization with the selected literature through iterative reading.
2. Identification and coding of key concepts related to deep learning, metacognition, and HOTS.
3. Development of conceptual themes and patterns emerging from the literature.
4. Comparison and interpretation of similarities, differences, and theoretical relationships among the identified themes.
5. Synthesis of findings into an integrated conceptual framework.

To enhance analytical trustworthiness, conceptual triangulation was employed by comparing perspectives from constructivist learning theory, reflective learning theory, self-regulated learning theory, and cognitive engagement frameworks. Furthermore, iterative interpretation and critical reflection were conducted throughout the analysis process to ensure conceptual consistency and alignment with the research objectives.

The final outcome of the analysis was an integrated conceptual model describing how deep learning approaches facilitate meaningful cognitive engagement, metacognitive regulation, and higher-order thinking development in higher education. The model serves as a theoretical framework that may guide educators, curriculum developers, and policymakers in advancing sustainable quality education and lifelong learning in accordance with SDG 4.

RESULTS AND DISCUSSION

Results

The thematic conceptual analysis revealed that advancing Sustainable Development Goal 4 (SDG 4) through higher education requires a reconstruction of student learning based on three interconnected dimensions: (a) meaningful cognitive engagement through deep learning, (b) metacognitive regulation as a mechanism for self-directed and lifelong learning, and (c) Higher-Order Thinking Skills (HOTS) development as a foundation for critical, adaptive, and innovative thinking. The findings indicate that deep learning is not merely an instructional strategy but a transformative educational orientation that supports sustainable quality education by fostering reflective, autonomous, and intellectually engaged learners.

The analysis further demonstrated that many higher education practices continue to reflect surface-learning tendencies characterized by information transmission, procedural assignments, and outcome-oriented assessment systems. Such practices often limit students' opportunities to develop reflective awareness, self-regulation, and higher-order thinking competencies. In contrast, deep learning environments encourage students to actively construct meaning, connect knowledge with authentic experiences, and engage in reflective inquiry, thereby contributing to the achievement of SDG 4 objectives related to quality learning and lifelong educational development.

Reconstruction of student learning orientation for sustainable quality education

The first major finding concerns the shift in student learning orientation from surface learning toward deep learning. The conceptual analysis identified several contrasting characteristics between these two learning orientations. Surface learning tends to emphasize memorization, task completion, and short-term academic achievement, whereas deep learning emphasizes conceptual understanding, reflective interpretation, and meaningful knowledge construction.

Table 1. Comparison between surface learning and deep learning orientations

Learning Dimension	Surface Learning Orientation	Deep Learning Orientation
Learning focus	Memorization of information	Conceptual understanding
Student motivation	Completing tasks and assessments	Meaningful learning and self-development
Cognitive process	Reproduction of knowledge	Knowledge construction and interpretation
Learning behavior	Passive and dependent	Active and reflective
Problem-solving approach	Procedural and linear	Analytical and adaptive
Knowledge transfer	Limited contextual application	Flexible application in authentic contexts
Reflection process	Minimal self-evaluation	Continuous reflective thinking
Role of lecturer	Dominant knowledge transmitter	Facilitator of inquiry and reflection

The findings suggest that reconstructing student learning through deep learning approaches contributes directly to sustainable quality education by shifting the focus from knowledge reproduction toward meaningful knowledge construction. This transformation aligns with SDG 4, which emphasizes the development of learners who are capable of critical reflection, lifelong learning, and adaptive problem-solving in diverse educational and professional contexts.

Metacognitive engagement in deep learning

The second finding highlights the central role of metacognitive regulation in supporting deep learning processes. The analysis revealed that students engaged in deep learning demonstrate greater awareness of their own cognitive processes through planning, monitoring, and evaluating learning strategies. Metacognitive engagement enables students to regulate their understanding, identify conceptual difficulties, and adapt learning strategies according to contextual learning demands.

The conceptual synthesis indicates that metacognition functions as an internal regulatory mechanism connecting cognitive engagement with reflective learning behavior. Students with stronger metacognitive awareness tend to demonstrate higher academic independence, stronger reflective capacity, and greater persistence when facing complex learning tasks.

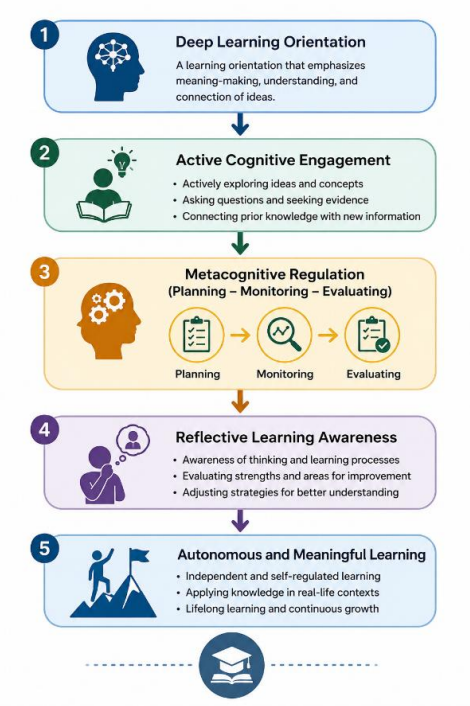

Figure 1. Conceptual relationship between deep learning and metacognitive regulation

The findings also indicate that reflective learning activities such as self-assessment, collaborative discussion, inquiry-based tasks, and authentic problem-solving contribute significantly to the development of metacognitive awareness. These activities encourage students to evaluate not only what they learn, but also how they learn.

Development of higher-order thinking skills (hots)

The third major finding concerns the relationship between deep learning approaches and HOTS development. The analysis revealed that deep learning environments consistently support higher-level cognitive processes, particularly analyzing, evaluating, and creating. HOTS development emerges when students are exposed to authentic problems, reflective inquiry, conceptual challenges, and open-ended learning tasks requiring interpretation and innovation.

The findings suggest that HOTS cannot develop effectively within procedural and lecture-dominated learning environments. Instead, higher-order thinking requires learning experiences that facilitate intellectual exploration, critical reflection, and adaptive reasoning. Deep learning approaches create conditions that encourage students to connect theoretical understanding with practical contexts and multidimensional problem-solving situations.

Table 2. Contribution of deep learning characteristics to higher-order thinking skills (hots) development

Deep Learning Characteristics	HOTS Dimension Developed	Description of Cognitive Development
Inquiry-based learning	Critical analysis	Encourages students to investigate problems, question assumptions, and analyze evidence critically
Reflective learning activities	Evaluative thinking	Develops students' ability to assess learning processes, arguments, and outcomes systematically
Authentic problem-solving	Adaptive reasoning	Strengthens the capacity to respond flexibly and effectively to complex real-world situations
Conceptual exploration	Analytical interpretation	Promotes deeper understanding through interpretation and connection of conceptual knowledge
Collaborative discussion	Argumentative reasoning	Enhances the ability to construct, defend, and evaluate arguments through academic interaction
Project-based investigation	Creative thinking	Stimulates innovation, idea generation, and solution design through experiential learning
Self-regulated learning	Decision-making ability	Supports independent judgment and strategic decision-making during the learning process

Source: Conceptual synthesis of deep learning and HOTS literature (2022–2026).

The conceptual analysis further indicates that HOTS development is strengthened when metacognitive regulation is integrated into the learning process. Students who consciously monitor and evaluate their thinking processes are more capable of engaging in analytical reasoning, generating alternative solutions, and constructing innovative ideas.

Integrated framework for advancing SDG 4 through deep learning

The final finding of this study is the formulation of an integrated conceptual framework for advancing SDG 4 through deep learning approaches. The framework positions deep learning, metacognitive regulation, and HOTS as interconnected dimensions of sustainable and transformative learning. Within this model, deep learning serves as the foundational orientation that promotes meaningful cognitive engagement, metacognition functions as a mechanism for lifelong and self-regulated learning, and HOTS represents the cognitive outcome required for addressing complex societal and professional challenges.

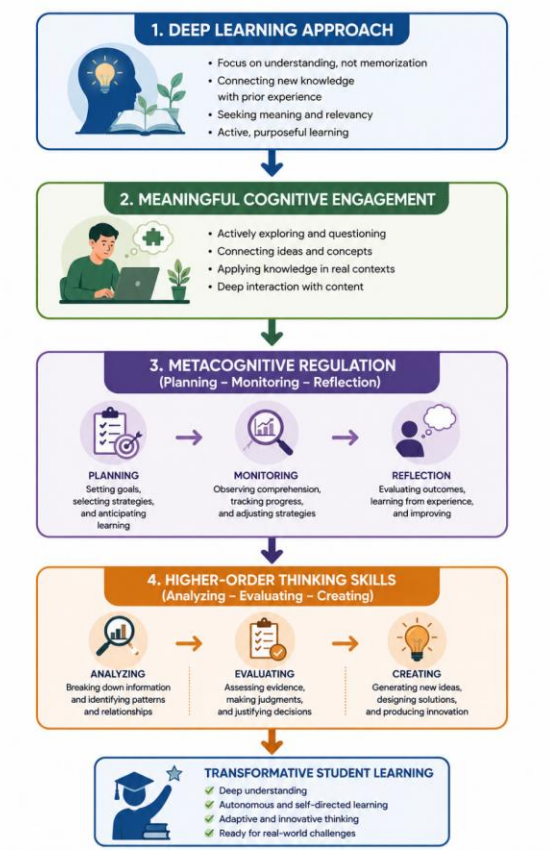

Figure 2. Integrated conceptual model of learning reconstruction

Discussion

This integrated model demonstrates that meaningful learning reconstruction in higher education requires more than instructional modification alone. It requires a paradigm shift in how learning is conceptualized, facilitated, and experienced by students. Deep learning approaches create opportunities for students to become reflective, autonomous, and intellectually adaptive learners capable of responding to complex academic and professional challenges.Overall, the findings confirm that the integration of deep learning approaches, metacognitive engagement, and HOTS development provides a holistic framework for reconstructing student learning in contemporary higher education contexts.

The findings of this study demonstrate that reconstructing student learning in higher education requires a fundamental shift from surface-oriented instruction toward deep learning approaches that emphasize cognitive engagement, reflective awareness, and higher-order thinking development. The results confirm that deep learning is not merely an instructional technique, but a transformative pedagogical orientation capable of reshaping how students understand knowledge, regulate their thinking processes, and respond to authentic learning challenges. This finding is consistent with the constructivist perspective presented in the literature review, which positions learning as an active process of meaning construction through reflection, interaction, and contextual experience (Biggs & Tang, 2022; Chen & Lien, 2022).

The first important discussion emerging from this study concerns the persistence of surface-learning practices in higher education. The results revealed that many contemporary learning environments remain dominated by procedural instruction,

lecturer-centered communication, and assessment systems emphasizing short-term achievement. This condition aligns with the concerns raised in the introduction, where students often focus on completing assignments and reproducing information rather than constructing conceptual understanding. Such findings indicate that despite the increasing discourse surrounding student-centered learning, instructional practices in many higher education contexts still struggle to facilitate meaningful cognitive engagement.

From a theoretical perspective, this phenomenon reflects the distinction between surface learning and deep learning originally conceptualized by Marton and Säljö and further strengthened by contemporary studies on deep learning pedagogy. The findings support the argument of Huang et al. (2023) and Zhao and Sullivan (2024), who emphasized that deep learning environments encourage students to integrate prior knowledge, critically interpret information, and engage actively in conceptual understanding. In contrast, surface learning tends to produce fragmented knowledge acquisition and limited knowledge transfer. The comparison presented in Table 1 clearly illustrates this contrast, particularly regarding learning motivation, cognitive processes, and problem-solving orientation. Students engaged in deep learning demonstrate stronger reflective engagement and greater intellectual autonomy compared with students operating within procedural learning environments.

Another significant discussion concerns the role of metacognitive regulation as an essential mechanism supporting deep learning processes. The findings revealed that students involved in deep learning approaches tend to demonstrate stronger planning, monitoring, and evaluation abilities during learning activities. This suggests that meaningful learning reconstruction cannot occur solely through content delivery or instructional innovation; rather, it requires students to become consciously aware of their own thinking processes. In this context, metacognition functions as a cognitive self-regulatory system that enables learners to evaluate understanding, recognize learning difficulties, and adapt strategies according to contextual demands.

This finding strongly corresponds with the metacognitive framework discussed in the literature review. Aydın and Demirer (2023) argued that students with higher metacognitive awareness are more capable of adapting to complex academic environments because they actively regulate their cognitive performance. Similarly, Panadero (2023) emphasized that self-regulated learning and metacognitive engagement contribute significantly to reflective thinking and intellectual independence. The conceptual relationship presented in Figure 1 demonstrates that deep learning orientation initiates active cognitive engagement, which subsequently strengthens metacognitive regulation and reflective learning awareness. In practical terms, this indicates that higher education institutions should not only focus on curriculum content, but also intentionally design learning experiences that encourage reflection, self-assessment, and inquiry-based engagement.

The findings further indicate that reflective learning activities, collaborative discussion, and authentic problem-solving contribute substantially to metacognitive development. This result is particularly important because it suggests that metacognition develops through active learning participation rather than through isolated theoretical instruction. Students become more reflective when they are challenged to justify arguments, evaluate learning strategies, and connect knowledge with authentic contexts. Therefore, the role of lecturers also changes significantly—

from knowledge transmitters into facilitators of reflective inquiry and cognitive exploration.

Another major discussion emerging from this study concerns the relationship between deep learning and Higher-Order Thinking Skills (HOTS). The findings revealed that deep learning environments consistently facilitate advanced cognitive processes, particularly analyzing, evaluating, and creating. This result confirms the theoretical assumption presented in the literature review that HOTS development depends on cognitively challenging learning environments characterized by inquiry, conceptual exploration, and authentic problem-solving activities (Sulaiman et al., 2023; Rahman et al., 2024).

The findings presented in Table 2 further demonstrate that different deep learning characteristics contribute to distinct dimensions of HOTS development. Inquiry-based learning supports critical analysis, reflective activities strengthen evaluative thinking, and project-based investigations stimulate creativity and innovation. These findings support Kim and Cross (2024), who argued that students engaged in deep learning approaches demonstrate stronger analytical reasoning and conceptual interpretation compared with students relying on memorization-oriented learning strategies. Importantly, the results also suggest that HOTS development is strengthened when metacognitive regulation is integrated into the learning process. Students who consciously monitor and evaluate their own thinking processes are more capable of generating alternative solutions, constructing arguments, and engaging in adaptive reasoning.

This integrated relationship among deep learning, metacognition, and HOTS represents one of the central contributions of this study. Previous research frequently examined these constructs separately, focusing either on instructional models, technological integration, or cognitive outcomes. However, this study demonstrates that these three dimensions are dynamically interconnected and mutually reinforcing within meaningful learning reconstruction. The integrated conceptual model presented in Figure 2 illustrates that deep learning serves as the foundational orientation driving metacognitive engagement and higher-order thinking development simultaneously.

From a pedagogical perspective, this integrated framework suggests that meaningful learning transformation requires systemic changes in how learning is conceptualized and facilitated within higher education. Traditional lecture-dominated environments may be insufficient for developing reflective and adaptive learners because they provide limited opportunities for inquiry, self-regulation, and authentic cognitive challenge. Instead, learning environments should be intentionally designed to promote collaborative exploration, reflective discussion, project-based investigation, and contextual problem-solving. Such approaches enable students to become active participants in knowledge construction rather than passive recipients of information.

The discussion also highlights the relevance of this conceptual reconstruction for professional and vocational higher education settings. As identified in the introduction, many practice-oriented disciplines continue to prioritize technical competence and procedural performance while giving insufficient attention to reflective awareness and analytical reasoning. The findings of this study suggest that professional competence alone is no longer adequate in contemporary higher education contexts. Students must also develop adaptive thinking, reflective

judgment, and decision-making abilities to respond effectively to dynamic professional challenges. Therefore, integrating deep learning approaches into vocational and professional education may strengthen not only operational competence but also intellectual adaptability and lifelong learning capacity.

Nevertheless, this study has several limitations that should be acknowledged. As a conceptual qualitative study, the findings are based on theoretical synthesis and interpretative analysis rather than empirical measurement of student performance (Biggs et al., 2021). Consequently, the proposed conceptual framework requires further validation through empirical research conducted in diverse higher education contexts. Future studies may examine how deep learning approaches influence metacognitive awareness and HOTS development across different disciplines, learning environments, and cultural contexts (Brown, 2017). Quantitative or mixed-methods investigations may also provide additional evidence regarding the effectiveness of the proposed framework in improving student learning outcomes (Docktor & Mestre, 2014). Overall, the findings confirm that the integration of deep learning, metacognitive engagement, and HOTS provides a comprehensive framework for advancing SDG 4 in higher education. By fostering reflective, autonomous, and critically engaged learners, this framework supports sustainable quality education and strengthens the capacity of graduates to contribute effectively to social, economic, and environmental sustainability in the twenty-first century (Dwivedi et al., 2021).

CONCLUSION

Fundamental Finding: This study demonstrates that advancing Sustainable Development Goal 4 (SDG 4) in higher education requires a reconstruction of student learning through deep learning approaches that foster meaningful cognitive engagement, metacognitive regulation, and Higher-Order Thinking Skills (HOTS). The findings indicate that learning transformation occurs when students actively engage in reflective inquiry, conceptual understanding, and authentic problem-solving rather than relying on memorization and procedural task completion. Furthermore, metacognition serves as a critical mechanism linking deep learning with HOTS development by enabling learners to plan, monitor, and evaluate their own learning processes. The integration of deep learning, metacognition, and HOTS provides a comprehensive framework for developing reflective, autonomous, and intellectually adaptive learners capable of responding to the challenges of contemporary higher education and sustainable development. **Implications:** The findings offer important implications for higher education institutions, educators, curriculum developers, and policymakers. Learning environments should be intentionally designed to promote inquiry-based learning, reflective practice, collaborative knowledge construction, and authentic problem-solving experiences. Such approaches can strengthen students' lifelong learning capacities, critical thinking abilities, and adaptability, thereby contributing to the achievement of SDG 4 and the broader agenda of sustainable educational transformation. **Limitations:** This study is limited by its conceptual and literature-based nature. The proposed framework was developed through theoretical synthesis and thematic conceptual analysis rather than empirical investigation. Consequently, the findings should be interpreted as a conceptual contribution that requires further validation in diverse higher education contexts. **Future Research:**

Future studies are encouraged to empirically examine the proposed framework across different academic disciplines, institutional settings, and cultural contexts. Quantitative, qualitative, and mixed-methods research designs may provide additional evidence regarding the effectiveness of deep learning approaches in enhancing metacognitive awareness, HOTS development, and sustainable learning outcomes. Further research may also explore how digital learning environments and project-based learning models contribute to advancing SDG 4 through transformative higher education practices.

AUTHOR CONTRIBUTIONS

Conceptualization, **Sri Usodoningtyas and Ekohariadi;** methodology, **Sri Usodoningtyas, Maspiyah, and Ratna Suhartini;** literature investigation and data curation, **Sri Usodoningtyas, Luthfiyah Nurlaela, and Tri Wrahatnolo;** formal analysis, **Sri Usodoningtyas, Ekohariadi, and Maspiyah;** writing—original draft preparation, **Sri Usodoningtyas;** writing—review and editing, **Ekohariadi, Maspiyah, Ratna Suhartini, Luthfiyah Nurlaela, and Tri Wrahatnolo;** visualization, **Sri Usodoningtyas and Ratna Suhartini;** supervision and validation, **Ekohariadi and Luthfiyah Nurlaela.** All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of ChatGPT (OpenAI) as a language-support tool during the preparation of this manuscript. The tool was utilized solely to assist with language refinement, grammar checking, and improving the clarity and readability of the text. ChatGPT was not involved in the research design, data collection, data analysis, interpretation of findings, or the generation of research results. All AI-assisted outputs were carefully reviewed, verified, and revised by the authors to ensure accuracy, academic integrity, and compliance with ethical standards. The authors take full responsibility for the content of this manuscript and all conclusions presented herein.

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