Bridging the Gap in Deep Learning Implementation: Design of Scientific Investigation Training for Science Teachers

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Abstract. The transformation of science education within the Deep Learning policy framework requires a fundamental reconstruction of teachers' pedagogical practices toward authentic, reflective, and contextual scientific inquiry. This study aims to develop the content and design of a Deep Learning–Based Scientific Inquiry training model for science teachers to bridge the gap between policy expectations and classroom practices. A context analysis study was conducted using qualitative document analysis of the Regulation of the Minister of Education No. 1 of 2026 on Process Standards, the Academic Manuscript of Deep Learning, the Science Learning Outcomes document, and theoretical frameworks on levels of inquiry and teacher professional development. Data were analyzed through reduction, categorization, and conceptual synthesis to formulate an epistemologically and pedagogically coherent training model. Findings indicate that deep learning in science positions science process skills as the epistemological pathway for constructing conceptual understanding through the cycle of understanding–applying–reflecting. However, classroom practices remain predominantly procedural, resembling cookbook laboratory activities. To address this challenge, the DINAMIS training model (Identification–Integration–Analysis–Simulation–Implementation–Self Reflection) was developed by adapting the Experiential Learning Cycle into a discipline-specific professional development framework. The model demonstrates vertical coherence (from conceptual understanding to reflective practice) and horizontal integration (deep learning principles, science process skills, and levels of inquiry). Conceptually and practically, this training design has the potential to strengthen science teachers' conceptual and implementative capacities in facilitating authentic inquiry, thereby enhancing students' scientific literacy and higher-order thinking skills.
Keywords: deep learning, scientific inquiry, teacher professional development, science process skills.

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1. Introduction

The transformation of science learning that is aligned with the deep learning policy demands fundamental changes in teachers' pedagogical practices, particularly in facilitating authentic, reflective, and contextual scientific investigations (Pemendikdasmen, 2025; 2026). In this new paradigm, science is no longer understood merely as the transmission of conceptual content, but rather as a process of knowledge construction based on scientific practices, evidence-based argumentation, and contextual decision-making (OECD, 2023; NRC, 2012). Conceptually, deep learning emphasizes the integration between conceptual mastery, scientific practice, collaboration, and higher-order thinking skills in the context of real-world problems (Fullan, Quinn, & McEachen, 2021). Therefore, within the science education framework, process skills or scientific investigations are positioned as the primary epistemological instruments to acquire understanding, so cognitive aspects and process skills must be delivered in a unified whole (BSKAP, 2025). This orientation aligns with the "science as practice" paradigm which places inquiry and argumentation at the core of

scientific literacy, thus instructional practices need to shift from a procedural-reproductive model towards an investigative-reflective one.
Although inquiry remains the main epistemological foundation, various studies show that its implementation in schools is often reduced to structured laboratory activities with minimal conceptual exploration (Crawford, 2014). Empirical findings confirm that science teachers still face difficulties in transforming scientific investigations from procedural models into learning experiences that demand complex reasoning and metacognitive reflection (Tekkumru-Kisa, Stein, & Schunn, 2015). This phenomenon is often found in the form of a "cookbook laboratory," where students only follow procedural steps without active involvement in problem formulation, investigation design, or critical interpretation of data (Browner et al., 2012; Hofstein, & Lunetta, 2004). This limitation in pedagogical capacity becomes a major barrier for students to experience the high-level cognitive processes necessary to build robust conceptual understanding and meaningful scientific literacy.

Professional development literature affirms that effective interventions for science teachers must focus on strengthening disciplinary content, active practice experiences, and continuous reflection (Darling-Hammond & Hyler, 2020). Strengthening Pedagogical Content Knowledge (PCK) is a key determinant for teachers to be able to design scientific investigations that are both contextual and conceptual (Chaitidou & Peikos, 2026).). As asserted by Fullan, Quinn, & McEachen (2021), pedagogical transformation cannot be achieved solely through curriculum innovation, but requires the reconstruction of teachers' professional capacity through collaborative and experience-based practices. Therefore, training for junior high school science teachers is a necessity that must be based on three main needs: (1) epistemological needs to reconstruct the understanding of the nature of science as a dynamic process, (2) pedagogical needs to equip facilitation strategies for scientific work and authentic assessment, and (3) professional needs to build continuous reflective learning communities (Rubini et al., 2019; Suyanto & Sugiarto, 2022).

However, previous studies indicate that current deep learning training programs are still generic and have not been fully designed specifically according to the epistemological characteristics of science subjects. To date, not many Deep Learning training models have explicitly integrated the principles of deep learning with science process skills and the spectrum of levels of inquiry as the hallmark of science learning. Most training tends to emphasize administrative aspects of the curriculum or general active learning strategies, without reconstructing scientific investigation as the center of science learning. This gap is the space of novelty for this research. Unlike previous research which tends to position deep learning as a general pedagogical framework or examines inquiry separately from teacher professional development design, this study is a preliminary step in developing a discipline-specific training model that explicitly integrates deep learning principles (mindful, meaningful, and joyful), the understand–apply–reflect learning experience, science process skills, and the spectrum of levels of inquiry into a single, coherent conceptual-operational framework.

Until now, there has been no science teacher training model that systematically places scientific investigation as the core epistemological mechanism in implementing deep learning, while simultaneously translating it into an applicable and contextual experiential learning-based training design. Thus, this study serves as a foundation for constructing an integrative training model combining national policy, science epistemology, and teacher professional development theory, bridging the gap between normative policy demands and authentic investigative practices in science classrooms. Strategically, teacher training is positioned as a systematic intervention to bridge the gap between deep learning policy demands and classroom practice realities. Without contextual and practice-oriented training support, policy implementation risks being reduced to normative discourse with no substantive impact on the quality of scientific investigations in the classroom (Rubini et al., 2019).

Therefore, this study aims to develop the content and design of a structured, reflective, and empirically needs-based training to produce an applicable model for strengthening science teacher competencies. Ultimately, this model is expected to increase teachers' pedagogical capacity in designing, facilitating, and assessing scientific investigations authentically, thereby encouraging the profound development of students' higher-order thinking skills and scientific literacy.

2. Method

Research Design

This study uses a qualitative approach with a context analysis study design that aims to develop a conceptual model and Deep Learning training design based on scientific investigations for junior high school science teachers. Context analysis was chosen because this study does not merely describe policy, but performs a conceptual synthesis of various normative and theoretical documents to produce an epistemologically and pedagogically coherent training model design. Methodologically, this study is rooted in the tradition of qualitative document analysis which allows for the systematic exploration of meanings, conceptual structures, and relations between policy and theoretical frameworks. This design is relevant to answer the research question: how to design a science teacher training model that is aligned with the principles of Deep Learning and the characteristics of scientific investigation as the core epistemology of science?

Data Sources

The research data sources consisted of primary and secondary documents analyzed purposively based on their relevance to the study focus. Document selection was carried out based on the criteria: 1) Direct relevance to science learning and deep learning, 2) Possessing academic/policy authority, 3) Representative of the epistemological and pedagogical frameworks analyzed. The analyzed documents included national education policy documents as well as theoretical and empirical documents. National policy documents consist of: 1) Ministerial Regulation of Primary and Secondary Education of the Republic of Indonesia No. 1/2026 on Process Standards; 2) The Academic Manuscript of Deep Learning in Indonesia; 3) The Phase D Science Learning Outcomes Document. The Theoretical and Empirical documents consist of: 1) The Framework for K-12 Science Education (NRC, 2012); 2) Level of Inquiry Theory (Wenning, 2011); 3) Experiential Learning Cycle Theory (Kolb, 2015).

Analysis Procedure and Reduction of Data

The analysis was conducted through systematic stages, namely data reduction, conceptual categorization, comparative analysis and integrative synthesis, and model construction. Reduction was carried out to focus the data on aspects relevant to the construction of the training model. Researchers identified meaning units related to: 1) Deep Learning Principles, 2) The structure of the understand–apply–reflect learning experience, 3) Characteristics of science process skills, 4) The spectrum of levels of inquiry, 5) Principles of teacher professional development.

Conceptual Categorization

Conceptual categorization is a process that allows the identification of intersections and discrepancies between documents. The meaning units were then grouped into thematic categories, including: 1) Epistemological dimensions (nature of science, knowledge construction); 2) Pedagogical dimensions (instructional design, inquiry facilitation); and 3) Professional dimensions (teacher competence and continuous development).

Comparative Analysis and Integrative Synthesis

Comparative analysis and synthesis were carried out using a theoretical integration approach, combining policy and theoretical frameworks into an operational conceptual model. This stage is the core of the analysis. Researchers conducted: 1) Vertical coherence analysis of primary education policies, then analyzed science learning outcomes and their pedagogical practices; 2) Horizontal coherence analysis, which is the relationship between deep learning, science process skills, and levels of inquiry; and 3) Conceptual synthesis to formulate training design principles.

Model Construction

The results of the synthesis were translated into a training design based on the Experiential Learning Cycle, which was elaborated into the DINAMIS model (Identification–Integration–Analysis–Simulation–Implementation–Self Reflection). At this stage, explicit mapping was carried out between: 1) The stages of Kolb's cycle; 2) The teacher competencies developed; 3) Training activities; and 4) Expected outcomes. This research is conceptual-analytical, where the researcher acts as the main instrument in interpreting and synthesizing documents. Therefore, reflexivity is maintained by basing all interpretations on explicit references and academically verified theoretical frameworks.

The research outputs include: 1) An integrative conceptual model of scientific investigation-based Science Deep Learning; 2) The DINAMIS training design based on the Experiential Learning Cycle; 3) Mapping of science teacher competency needs (conceptual and implementative).

3. Results and Discussion

Initially, a review was conducted on The Deep Learning Academic Manuscript in Indonesia and Process Standards for the content of the learning process aspects. Based on the review results, it can be seen that there is an intersection indicating that learning is designed as an experience that is mindful, meaningful, and joyful through the stages of understanding–applying–reflecting, in an environment that is interactive, inclusive, collaborative, and based on partnerships and technology, with the aim of fostering self-regulation, knowledge transfer capability, religious character, character building, and 21st-century competencies (creativity, critical reasoning, communication, and collaboration) which are expanded into the 8 dimensions of graduate profiles.

Conceptually, the academic manuscript and process standards lead to the transformation of learning: 1) Transformation from teacher-centered to deep learning student-centered; 2) Integration among cognitive, affective, and social aspects; 3) Strengthening student agency/leadership or learning independence; 4) Learning as an ongoing and reflective process.

The Process Standards and Academic Manuscript show that the understand–apply–reflect learning experience has a two-layered function: (1) as generic and cross-disciplinary policy norms, and (2) as a conceptual-operational framework explaining the mechanism of knowledge construction, character development, and self-regulation systematically. Process Standards provide the minimum structure that must be present in learning, while the Academic Manuscript enriches this structure with epistemological, metacognitive, and contextual dimensions that make learning truly deep. Thus, the synthesis of both produces a learning experience model that not only requires learning activities, but demands a transformation in how students consciously, contextually, and sustainably construct, apply, and reflect upon knowledge.

The analysis results give rise to generic learning characteristics that apply to all subjects and must occur in all classrooms. Meanwhile, science subjects have specific characteristics in their implementation. Therefore, to understand the deep learning process, it is necessary to examine the Phase D science learning outcomes manuscript in synergy with the deep learning academic manuscript and process standards. Based on the results of the analysis of these three documents, it is possible to determine the position and role of scientific inquiry as the core pedagogical mechanism bridging deep learning principles with the scientific characteristics of science.

The principle of being mindful is realized when students understand the purpose of the investigation, formulate questions, and manage their learning strategies during the investigation process. The principle of being meaningful is achieved when science concepts are applied to explain real phenomena or solve contextual problems through experimental activities, data analysis, and evidence-based decision-making. Meanwhile, the joyful principle is present in a challenging yet supportive learning atmosphere, when students are actively involved in authentic exploration, collaboration, and communication of findings.

Operationally, the understand–apply–reflect learning experience is inherently integrated with the science process skills cycle. The understanding stage takes place through observing, questioning, and predicting phenomena. The applying stage is manifested in planning and conducting investigations, collecting and analyzing data to build scientific explanations. The reflecting stage aligns with process evaluation, interpretation of findings, and communication of results as forms of self-regulation and continuous improvement. Thus, process skills are not positioned as additions, but as the epistemological pathway to achieving complete science understanding.

The analysis results also affirm that science learning is integrated and contextual. Complex natural phenomena demand a multidisciplinary approach (physics, chemistry, biology) within a unit of inquiry framework, enabling students to build a holistic understanding of authentic issues such as climate change, energy, or environmental health. This integration strengthens the dimension of learning partnerships—involving teachers, peers, and the community—as well as optimizing technology as a tool for exploration and scientific communication.

Thus, this integrative conceptual model views science learning as a pedagogical ecosystem uniting: (1) deep learning principles; (2) the understand–apply–reflect cycle of learning experiences; and (3) inquiry-based science process skills as the hallmark of the discipline. It is these investigative characteristics that distinguish science from other subjects, simultaneously serving as the foundation for shaping students who are scientifically literate, critically thinking, reflective, and capable of making evidence-based decisions in real life.

Furthermore, the analysis results between the principles and learning experiences of deep learning with the level of inquiry presented by Wenning (2005) reveal that the deep learning process in the Academic Manuscript and Process Standards has a strong correlation with Wenning's spectrum of Levels of Inquiry. Deep learning is not a model separate from inquiry, but is a macro-framework compatible with the progression of inquiry levels. Deep learning drives learning to reach high levels of inquiry (Real-world & Hypothetical Inquiry).

The integrative synthesis of deep learning and Level of Inquiry can be seen in **Table 1.** Correlating them, the understanding phase aligns with initial-level inquiry which is still structured; the applying phase represents laboratory inquiry and real-world applications; while the reflecting phase intersects with hypothetical inquiry which requires testing explanations and self-regulation. The deep learning experience becomes an integrative framework bridging the demands of the Process Standards with high-level inquiry practices, ensuring science learning is truly characterized by meaningful process skills and scientific investigations. Therefore, deep learning can be positioned as a macro-framework that is conceptually compatible with the progression of inquiry levels and pedagogically demands a shift in learning control from teacher to student towards intellectual autonomy.

Table 1. Integrative Synthesis of Deep Learning and Level of Inquiry

Deep Learning Experience	Epistemological Orientation	Level of Inquiry	Teacher-Student Control Shift
Understanding	Concept construction	Discovery, Interactive Demonstration, and Inquiry Lesson	Teacher-dominant
Applying	Experimentation & real-world problem solving	Inquiry Lab → Real-world Application	Balanced
Reflecting	Metacognition & evaluation of conceptual explanations	Hypothetical Inquiry	Student-dominant

Note: Students also reflect by evaluating their learning and making meaning of their experiences, processes, and results.

A. Implications for Teacher Competency Needs

The integrative conceptual model of inquiry-based science deep learning requires a reorientation of teacher competencies, not only in content mastery but also in conceptual and implementative capacities in facilitating the entire scientific investigation process. The implications can be mapped into the following two main domains; 1) Conceptual Understanding Competence and 2) Practical Competencies (Pedagogical and Facilitative Skills).

1. Conceptual Understanding Competence

Teachers need to have a deep and integrated understanding of: a) the nature of science; b) Integration of Deep Learning Concepts: and c) Structure and Level of Inquiry.3)

a. The Nature of Science as Process and Product

Teachers must not only understand science concepts, laws, or theories, but also science epistemology—how scientific knowledge is built through observation, hypothesis testing, data analysis, and evidence-based argumentation. During this scientific investigation process, students' scientific attitudes will emerge. Without this understanding, learning tends to revert to content transmission, not investigation.

b. Integration of Deep Learning Principles

Science teachers must conceptually understand the meaning of: 1) Mindful, related to the importance of self-regulation, intrinsic motivation, and awareness of learning goals; 2) Meaningful, related to connecting science concepts with authentic and cross-disciplinary contexts; and 3) Joyful, related to the role of positive emotions in improving retention and cognitive engagement. Mastering these deep learning concepts is essential to serve as a foundation in designing authentic understand–apply–reflect learning experiences.

c. Structure and Level of Inquiry

Teachers need to understand the spectrum of inquiry levels (from discovery to hypothetical inquiry) to adjust the complexity of investigations to the cognitive readiness of students. Without this framework, inquiry facilitation could become either too open or conversely too structured

2. Practical Competencies (Pedagogical and Facilitative Skills)

In addition to conceptual understanding, teachers need practical competencies to implement the model effectively.

a. Instructional Design Competence

Science teacher competencies in instructional design must include the ability to: 1) Design units of inquiry based on contextual issues; 2) Integrate concept understanding with science process skills; 3) Develop authentic assessments evaluating the investigation process, not just final results.

b. Inquiry Process Facilitation Competence

The teacher's role shifts from a knowledge transmitter to a learning facilitator. Teachers need to be skilled in: 1) Posing high-level guiding questions; 2) Guiding problem and hypothesis formulation; 3) Providing scaffolding during experiments; 4) Encouraging data-driven scientific argumentation; and 5) Managing reflective discussions.

c. Regulation and Reflection

Competence Because deep learning emphasizes reflection and self-regulation, teachers need to be able to: 1) Provide specific formative feedback; 2) Train students to conduct metacognitive reflection; and 3) Create a safe classroom culture for exploration and productive mistakes.

d. Collaborative and Technological Competence

Teachers are also required to be able to: 1) Build partnerships with fellow teachers and the community; 2) Integrate technology as a tool for investigation, data analysis, and scientific communication.

A further implication is that teacher training must not only focus on conceptual workshops, but must be designed based on the experiential learning cycle (experiencing–reflecting–conceptualizing–testing). Teachers need to experience the inquiry process themselves as learners to be able to facilitate it authentically.

Thus, teacher competency needs in this model are holistic and transformative:

1) Deeply understand science concepts and science epistemology.
2) Understand deep learning concepts.
3) Understand levels of inquiry as a progressive framework for developing cognition and science process skills.
4) Be skilled in designing and facilitating learning with scientific investigations.
5) Be capable of building a reflective, collaborative, and contextual classroom culture.

Without strengthening both dimensions—conceptual and implementative—science learning risks being reduced to mere procedural experimental activities, rather than inquiry processes building scientific literacy and deep scientific thinking skills.

B. Experiential Learning Cycle-Based Training Content and Competencies Design

Based on the results of theoretical reviews and policy document analysis, training content is designed to develop science teacher competencies conceptually, pedagogically, and reflectively so they can systematically implement scientific investigation-based deep learning. The training design needs to adopt an experiential learning and practice-based professional development approach, where teachers do not just receive materials, but directly experience the investigation process, design learning tools, implement them in simulations or guided practice, and collaboratively reflect upon the results (Kolb, 2015).

Developing these competencies stems from the assumption that transforming learning practices is not enough through mere conceptual knowledge transfer; rather, it requires reconstructing professional experiences through reflective and contextual learning cycles (Kolb, 2015; Garet, et al., 2001). Substantively, the competencies developed cover four main achievements. First, teachers understand the deep learning concept alongside its implications for science learning implementation. This understanding covers the mindful, meaningful, and joyful principles, as well as the understand, apply, and reflect learning experiences. Second, teachers analyze the connection between science process skills and deep learning, so that scientific investigation is not positioned merely as a procedural activity, but as a vehicle for conceptual meaning construction. Third, teachers understand the levels of inquiry (Wenning, 2011) as a progressive framework for developing cognition and science process skills. Fourth, teachers progress from analyzing example teaching modules, simulating learning, and independently developing modules, to designing authentic assessments aligned with the characteristics of scientific investigations. Eighth [Note: Source implies eighth, but follows fourth], teachers conduct self-reflection to construct understanding and design follow-up classroom implementation.

The training design adapts the Experiential Learning Cycle (Kolb, 2015) which consists of concrete experience, reflective observation, abstract conceptualization, and active experimentation. To improve operability in the context of science teacher training, the cycle is elaborated into the **DINAMIS** model (I**d**entification, **I**ntegration, **An**alysis, Si**m**ulation, **I**mplementation, and **S**elf Reflection). This model maintains epistemological coherence with Kolb's theory, but provides a more explicit pedagogical structure suited to the needs of practice-based teacher professional development in Indonesia.

Identification. This stage facilitates teachers to identify and construct an initial understanding of deep learning concepts and the level of inquiry model. Activities involve concept exploration, critical discussions, and mapping characteristics of science learning that meet deep learning principles. The expected result is a conceptual mastery serving as the foundation for pedagogical integration.

Integration. Teachers integrate science process skills, levels of inquiry, and deep learning experiences. This integration is carried out through analyzing and designing example activities based on laboratory practicums. This stage represents the abstract conceptualization process in Kolb's framework, where teachers construct integrated conceptual schemas between cognitive and procedural dimensions.

Analysis. Teachers analyze teaching modules implementing the level of inquiry model within a deep learning framework (e.g., on the topic of photosynthesis). The analysis focuses on the coherence between learning objectives, investigative activities, science process skills, and assessments. This stage strengthens teachers' pedagogical reasoning capabilities.

Simulation. Teachers simulate learning activities based on provided teaching modules. Simulation enables a concrete experience in a safe environment, allowing teachers to test conceptual understanding through guided practice. The outcome is a simulation report reflecting the alignment between design and implementation.

Implementation. Teachers independently develop teaching modules and implement them in the classroom. Products produced include teaching module documents, assessment instruments, and implementation reports. This stage represents active experimentation, where teachers test their designs in authentic learning contexts.

Self Reflection. Teachers reflect on their understanding, implementation practices, and their impact on student learning. Reflection is directed at gaps between design and practice, as well as planning for follow-up. This stage becomes a crucial self-regulation mechanism in continuous professional development.

Significant improvements in students' scientific literacy occur when teachers are able to explicitly integrate science process skills in inquiry learning (Suryawati & Osman, 2018). However, other studies reveal that many teachers still apply "procedural guided inquiry" tending to resemble cookbook laboratories, thereby failing to encourage higher-order cognitive involvement (Rahayu, 2017). These findings reinforce the urgency of the Integration, Analysis, and Simulation phases within the DINAMIS design to shift teacher practices from mere procedural activities toward reflective and meaningful investigations. Furthermore, research results by Widodo & Riandi (2013) demonstrate that the success of pedagogical innovation is highly determined by professional development models that are participatory, based on real practice, and continuous. This aligns with characteristics of effective training emphasizing active learning, coherence, content focus, and collective participation (Darling-Hammond et al., 2022). Therefore, the Implementation and Self-Reflection phases in DINAMIS are designed to ensure training does not stop at the conceptual level, but continues to documented and systematically reflected classroom practices. Thus, the DINAMIS design is positioned as a contextual intervention model bridging these gaps through a structured step-by-step approach based on the Experiential Learning Cycle adapted specifically for the discipline.

In summary, the DINAMIS model framework for deep learning implementation training using scientific investigation for science teachers can be seen in **Table 2.**

Table 2. The DINAMIS Model Framework for Science Teachers' Deep Learning Training Using Scientific Investigation

Phase	Developed Competencies	Core Activities	Expected Outcomes	Recent Theoretical & Empirical Foundations (2020–2025)
Identification	Conceptual understanding of Deep Learning principles (*mindful*, *meaningful*, *joyful*) and Levels of Inquiry	Directed document analysis; concept mapping; comparison of inquiry levels	Mastery of concepts and the ability to classify science learning based on inquiry levels	Academic Paper on deep learning (2025); Inquiry progression (Wenning); Coherent professional development design (Kolb, 2015)
Integration	Connecting science process skills (SPS), inquiry levels, and deep learning experiences	Designing practicum-based inquiry scenarios; collaborative alignment mapping	Integrated lesson plans demonstrating coherence between SPS and inquiry levels	Science practices framework (NRC, 2012; OECD, 2023); Process Standards
Analysis	Evaluating inquiry-based teaching modules within the deep learning framework	Structured critical analysis of sample modules; review of objective-process-assessment alignment	Analysis report demonstrating pedagogical coherence	Pedagogical reasoning and instructional alignment (Darling-Hammond et al., 2022)
Simulation	Practicing inquiry-based deep learning in a controlled environment	Microteaching; peer feedback; structured reflection	Simulation report and reflective synthesis	Active learning in professional development (Darling-Hammond et al., 2022); Experiential professional learning (Kolb, 2015); Process Standards

Implementation	Developing and implementing inquiry modules independently	Independent module development; classroom implementation; assessment design	Teacher-developed teaching modules; implementation report; aligned assessment instruments	Practice-based professional development; Sustainability of teacher practice change (Fullan, Quinn, & McEachen, 2021); Inquiry assessment framework (OECD, 2023; Process Standards)
Self-Reflection	Reflective professional growth and follow-up planning	Guided reflection journal; gap identification; formulating improvement plans	Reflection document and follow-up action plan	Reflective professionalism (Darling-Hammond et al., 2022); Teacher agency in educational reform (Process Standards)

The DINAMIS model shows vertical and horizontal coherence. Vertically, each stage builds competence from conceptual understanding to reflective practice. Horizontally, each stage integrates three main dimensions: (1) deep learning principles, (2) science process skills, and (3) level of inquiry. Thus, the training is not fragmentary, but forms a complete pedagogical system. This approach aligns with teacher professional development theories emphasizing the importance of coherence, active learning, content focus, and collective participation (Garet, et al., 2001). In addition, integrating scientific investigation in science learning aligns with recommendations from the National Research Council (2012) and BSKAP (2025) positioning scientific practices or process skills as the core of science learning.

Overall, the DINAMIS training design not only aims to improve teachers' pedagogical knowledge but to transform learning practices through cycles of experience, reflection, conceptualization, and experimentation. Hence, this training has the potential to produce sustainable changes in practice, impacting the improvement of students' learning outcomes in dimensions of conceptual understanding and investigative skills. Therefore, the main contribution of this study lies in providing a discipline-specific training model that not only explains what Deep Learning is, but also how to concretely implement it in scientific investigation-based science learning. Conceptually, this research broadens the Deep Learning discourse by asserting that pedagogical transformation cannot be detached from strengthening teachers' capacities to manage inquiry progressively according to the level of inquiry (Wenning, 201). Practically, this research offers a systematic and contextual training design to enhance students' scientific literacy through strengthening science teacher competencies. Thus, this study provides empirical contributions to the literature on teacher professional development in Indonesia while enriching the scientific investigation-based Deep Learning implementation model.

Conclusion and Recommendations

Conclusion

This study affirms that the transformation of Deep Learning (pembelajaran mendalam) in the context of science cannot be understood merely as a shift in general pedagogical approaches, but as an epistemological reconstruction of science learning placing inquiry-based scientific investigations at the core of the learning process. Analysis of Process Standards, the Academic Manuscript of Deep Learning, and Science Learning Outcomes shows strong normative coherence: learning must be mindful, meaningful, and joyful through understand–apply–reflect experiences. However, theoretical and empirical findings indicate there remains a gap between policy demands and classroom practices, especially the tendency to reduce inquiry into procedural activities (cookbook laboratory) lacking epistemic reflection and evidence-based argumentation.

The integrative conceptual model developed in this study positions science process skills as an epistemological pathway to achieve complete conceptual understanding. Thus, understanding and investigation are not separated, but integrated into a unified pedagogical system based on levels of inquiry. To bridge the implementative gap, this study produces the DINAMIS training design (Identification–Integration–Analysis–Simulation–Implementation–Self Reflection) which adapts the Experiential Learning Cycle in a discipline-specific manner to the science context. This model demonstrates vertical coherence (from conceptual understanding to reflective practice) and horizontal coherence (integration of deep learning principles, process skills, and levels of inquiry), thus possessing the potential to sustainably transform teacher practices.

Therefore, the main contribution of this study lies in the development of a contextual and applicable training model that strengthens the conceptual and implementative capacities of science teachers in facilitating authentic scientific investigations. Overall, the successful implementation of Deep Learning in science heavily depends on the professional readiness of teachers to understand and facilitate inquiry as a knowledge construction process. Without systematic strengthening of conceptual and implementative competencies, policy potentially stops at the normative level. Conversely, through coherent, reflective, and practice-based training designs like DINAMIS, pedagogical transformation toward investigative, meaningful, and continuous science learning becomes much more achievable.

Recommendations

Based on the findings and conceptual synthesis of this study, several strategic recommendations can be proposed:

1. Strengthening the implementation of Deep Learning must be accompanied by discipline-specific professional development programs, rather than generic cross-subject training;
2. Training trials for empirical testing of the content and design of the created training activities;
3. Science teacher training needs to adopt experience-based models (experiential and practice-based PD) like DINAMIS, enabling teachers to experience, reflect on, and test investigative practices authentically;
4. Training focus should encompass strengthening science epistemology, designing phenomenon-based units of inquiry, facilitating scientific argumentation, and developing process-based assessments; and
5. Science teachers need to gradually increase the complexity of inquiry corresponding to the spectrum of inquiry levels so students develop from guided inquiry toward more open and reflective inquiry.

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