

Elementary Teachers' Perceptions, Readiness, and Challenges in Using Interactive Deep Learning–STEM-PBL Modules

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Abstract: This study examines elementary school teachers' perceptions, readiness, and challenges in using and developing interactive teaching modules based on pedagogical deep learning integrated with Problem-Based Learning (STEM-PBL) to support scientific literacy and communication. This study adopted an exploratory cross-sectional design, collecting data from 100 elementary teachers in Lampung Province, Indonesia, through online questionnaires, document analysis, and in-depth interviews. The findings indicate that while most teachers demonstrate positive perceptions toward interactive Deep Learning–STEM-PBL modules, their readiness to implement such approaches varies and is constrained by limited pedagogical competence, instructional design skills, and professional development opportunities. Document analysis further reveals a clear perception–practice gap, as most teaching modules do not yet explicitly integrate deep learning principles and STEM-PBL stages. Key challenges include insufficient training, time constraints, limited instructional references, and inadequate institutional support. Based on these findings, this study proposes a Teacher Readiness Framework for Deep Learning–STEM-PBL, which conceptualizes readiness as the interaction between teachers' perceptions, multidimensional pedagogical capacities, and structural–institutional conditions that influence instructional practice outcomes.

Keywords: Elementary Teachers; Teacher Readiness; STEM-PBL; Deep Learning; Instructional Modules

Abstrak: Penelitian ini mengkaji persepsi, kesiapan, dan tantangan guru sekolah dasar dalam menggunakan dan mengembangkan modul pembelajaran interaktif berbasis pembelajaran mendalam pedagogis yang terintegrasi dengan Pembelajaran Berbasis Masalah (STEM-PBL) untuk mendukung literasi ilmiah dan komunikasi. Penelitian ini menggunakan desain eksploratif cross-sectional, mengumpulkan data dari 100 guru sekolah dasar di Provinsi Lampung, Indonesia, melalui kuesioner online, analisis dokumen, dan wawancara mendalam. Hasil penelitian menunjukkan bahwa meskipun sebagian besar guru memiliki persepsi positif terhadap modul pembelajaran interaktif Deep Learning–STEM-PBL, kesiapan mereka untuk menerapkan pendekatan tersebut bervariasi dan dibatasi oleh keterbatasan kompetensi pedagogis, keterampilan desain instruksional, dan kesempatan pengembangan profesional. Analisis dokumen juga mengungkapkan adanya kesenjangan yang jelas antara persepsi dan praktik, karena sebagian besar modul pembelajaran belum secara

eksplisit mengintegrasikan prinsip-prinsip pembelajaran mendalam dan tahap-tahap STEM-PBL. Tantangan utama meliputi pelatihan yang tidak memadai, keterbatasan waktu, referensi instruksional yang terbatas, dan dukungan institusional yang tidak memadai. Berdasarkan temuan ini, studi ini mengusulkan Kerangka Kesiapan Guru untuk Deep Learning-STEM-PBL, yang mengonseptualisasikan kesiapan sebagai interaksi antara persepsi guru, kapasitas pedagogis multidimensi, dan kondisi struktural-institusional yang memengaruhi hasil praktik instruksional.

Kata kunci: Guru Sekolah Dasar; Kesiapan Guru; STEM-PBL; Deep Learning; Modul Instruksional

Introduction

Science education at the elementary school level plays a central role in establishing the foundation of scientific literacy, critical thinking skills, and students' ability to analyze and solve problems using scientific methods (Schneegans, 2021). Early mastery of scientific concepts is believed to foster a generation that is adaptive, responsive to global issues, and capable of offering science-based solutions to real societal problems (Yulianti, 2017). However, data from the Programme for International Student Assessment (PISA) 2022 indicate that Indonesian students' scientific literacy remains below the (OECD, 2022) average, with a score of 396 compared to the OECD average of 489 in 2018 and 359 compared to the OECD average of 482 in 2022, signaling an urgent need to strengthen science learning at the elementary level. This condition is reinforced by previous studies indicating that only 20% of elementary school teachers feel confident in developing and planning innovative and contextual learning activities (Alawiyah, 2017). In addition, teachers' ability to apply scientific concepts effectively in classroom instruction remains limited (Qomariyah, 2025). Contrasts with the findings of research from (Sulistiani & Dewi, 2024), which states that the Professional Knowledge of Technology of Teachers, Teacher Self-Efficacy, and Teacher Technology Integration Performance at MIN 1 Malang City meet high criteria with PPT scores of 3.87 (77.4%), EF 3.54 (70.8%), and KIT 3.53 (70.6%). This is due to the unevenness of the education system in Indonesia.

The Indonesian government has sought to enhance science education within learning environments through the implementation of the Merdeka Curriculum. This curriculum emphasizes meaningful and contextual learning, as well as the development of character and 21st-century competencies. Project-based learning (PBL), which is a key feature of the Merdeka Curriculum, encourages students to be active, creative, and collaborative in solving problems (Kemendikbudristek, 2022; Permendikbudristek No. 12 of 2024). An approach that aligns closely with the spirit of the Merdeka Curriculum is deep learning, which emphasizes conceptual understanding, the application of critical thinking skills, collaborative practices, the development of reflective awareness, and the creation of enjoyable and relevant learning experiences (Bakhtiar, 2023; Prianto et al, 2022).

The development of interactive teaching modules has become a significant focus of instructional innovation in elementary schools, as reflected in the increasing number of publications related to interactive module development (Muhammad, 2023). Studies by Bakhtiar (2023) and Mulyono (2025) demonstrate that interactive modules designed for differentiated learning in Integrated Science and Social Studies (IPAS) content significantly improve students' learning outcomes, interests, and motivation. Empirical studies show that expert-validated 4D model-based modules are highly feasible for classroom use and foster engaging, participatory learning (Nugraha et al.,

2022). Other studies also confirm that technology-based interactive teaching materials, such as augmented reality and multimedia, can substantially enhance elementary students' interest, engagement, and conceptual understanding (Mukti, 2022; Nugraha et al., 2022).

Educators have increasingly integrated the Problem-Based Learning (PBL) model with the STEM (Science, Technology, Engineering, and Mathematics) approach to equip students with 21st-century skills, including critical thinking, problem-solving, and the application of knowledge (Smith et al., 2022; Su, 2024). Recent national and international studies confirm that the implementation of STEM-PBL enhances students' learning motivation, critical thinking skills, and scientific literacy outcomes (English, 2016; Hmelo-Silver, 2023). Research conducted in Indonesia further demonstrates that STEM integration in learning, particularly within the Merdeka Curriculum framework, encourages students to become more active, creative, and innovative in addressing technological challenges and everyday life problems (Hazima et al., 2024; Khairah et al., 2023).

Scientific literacy at the elementary school level is a critical indicator of educational quality, as it enables students to develop scientific ways of thinking (Schneegans, 2021). Vieira & Tenreiro-Vieira, (2016) and Al Sultan et al., (2021) review suggests a conceptual alignment between scientific literacy in elementary education and UNESCO's four pillars, with STEM-PBL offering a potential enhancement strategy. Nevertheless, significant challenges persist, particularly in students' critical thinking abilities and teachers' readiness to implement relevant instructional strategies. Research on deep learning module development reports comparable challenges, indicating that relatively few teachers possess adequate understanding and capacity to integrate technology and interdisciplinary approaches in science instruction (Bakhtiar, 2023).

Teachers' readiness to implement integrated learning approaches such as deep learning and STEM-PBL constitutes a central issue in advancing science education innovation at the elementary level. Many elementary school teachers have not yet fully understood interdisciplinary integration concepts or experience difficulties in designing instructional materials that align with deep learning and STEM-PBL principles (Larkin & Lowrie, 2023; Asim et al., 2025). Additional challenges include limited professional training opportunities, time constraints, insufficient references for teaching modules, minimal support from learning communities, restricted access to digital learning resources, and heavy administrative workloads (Estapa & Tank, 2017).

Unlike previous studies that examine STEM-PBL implementation, instructional module development, or teacher training in isolation, this study offers an integrated and empirical mapping of elementary teachers' perceptions, readiness, and challenges in implementing interactive Deep Learning-STEM-PBL modules. By employing a triangulated research design that combines survey data, instructional document analysis, and in-depth interviews, this study reveals a critical gap between teachers' positive perceptions and the actual quality of teaching modules used in classroom practice. This contribution extends the existing literature by providing a contextualized readiness framework that highlights key structural, pedagogical, and institutional barriers influencing STEM-PBL implementation at the elementary level, particularly within developing-country educational settings.

Therefore, this study seeks to address the following research questions: (1) What are elementary teachers' perceptions of interactive Deep Learning–STEM-PBL modules? (2) How are teachers ready to implement such modules? Moreover, (3) What challenges do teachers face in developing and using them?

Method

1. Research Method

This study employed an exploratory cross-sectional survey design to systematically map elementary school teachers' perceptions, readiness, and challenges in implementing interactive teaching modules based on Deep Learning integrated with STEM-PBL. This design was selected to capture teachers' conceptual understanding and instructional conditions at a single point in time, which is appropriate for examining readiness as a multidimensional construct rather than measuring causal effects (Olawale et al., 2023).

This study adopted an exploratory approach because empirical research simultaneously examining teachers' perceptions, readiness, and actual instructional practices related to Deep Learning–STEM-PBL at the elementary level remains limited. Therefore, this study focuses on generating an integrated empirical mapping that can serve as a foundation for the development of teacher readiness frameworks and future intervention studies.

2. Population and Sample

The population of this study consisted of all elementary school teachers in Lampung Province, Indonesia, totaling 51,992 teachers according to official data from the Central Statistics Agency. A sample of 100 elementary school teachers was selected using stratified random sampling to ensure representation across districts, school types (public and private), and teaching experience levels. The inclusion criteria required teachers to be actively teaching and to have prior experience in developing or using science teaching modules. The sample comprised teachers with less than five years (30%), five to ten years (45%), and more than ten years (25%) of teaching experience. The study employed this sampling strategy to enhance representativeness and facilitate exploratory mapping of readiness dimensions (Ilyasu & Etikan, 2021), while acknowledging that the sample size supports exploratory analysis rather than statistical generalization.

3. Research Instruments

Data were collected using three primary instruments: an online questionnaire, analysis of teaching materials, and in-depth interviews. The questionnaire consisted of 25 closed-ended items using a Likert scale and five open-ended questions. The study developed instrument items using STEM integration indicators (Honey et al., 2014) and Davison et al., (1995) framework. Experts assessed content validity, and reliability was confirmed through Cronbach's Alpha ($\alpha > 0.7$) using SPSS 26.

The study analyzed teaching modules, lesson plans, and student worksheets using an expert-validated rubric assessing Deep Learning dimensions, PBL stages, STEM reinforcement, curriculum alignment, and scientific communication. Materials were systematically categorized based on Davison et al., (1995) five integration types, with analysis emphasizing the presence of explicit Deep Learning and STEM-PBL indicators rather than quantitative quality scores.

The researchers conducted in-depth, semi-structured interviews with a purposively selected sub-sample of teachers based on the results of the survey and document analysis. The interviews explored teachers' experiences in developing interactive teaching modules grounded in Deep Learning and STEM-PBL. The study analyzed

interview data thematically by organizing responses into emergent key themes and strengthened data validity through triangulation.

4. Research Procedures

The study implemented the research procedure through several systematic stages, as follows:

Table 1. Stages of the Research Procedure

Stages	Activity Description
Preparation	Instrument development (questionnaires, document analysis rubrics, interview guidelines) and expert validation
Data Collection	Distribution of online questionnaires, collection of teaching documents, and conduct of interviews
Data Analysis	Descriptive statistical analysis of questionnaire data, content analysis of teaching documents, and thematic analysis of interview data
Triangulation and Validation	Data triangulation across sources and expert validation of the findings
Reporting	Compilation of research findings and formulation of recommendations

4. Data Analysis and Validity

Questionnaire data were analyzed using descriptive statistical techniques to identify patterns in teachers' perceptions, readiness, and challenges. Document analysis involved calculating the frequency and quality of the integration of deep learning principles and STEM-PBL. The study thematically analyzed interview data to enrich contextual insights into teachers' strategies and experiences.

Data validity was ensured through triangulation across data sources (questionnaires, documents, and interviews) and expert validation of the instruments and analysis results. All research procedures adhered to ethical principles, including informed consent, data confidentiality, and approval from local education authorities. Through this design and methodology, the study aims to provide robust empirical evidence on elementary school teachers' perceptions, readiness, and challenges in developing interactive deep learning-STEM-PBL teaching modules, as well as to serve as a foundation for future teacher training models and more contextually relevant and applicable instructional innovations.

Result and Discussion

1. Result

This study involved 100 elementary school teachers in Lampung Province, distributed across various districts and municipalities, with a composition predominantly of female teachers (60%) and male teachers (40%). Based on teaching experience, 30% of teachers had less than five years of experience, 45% had between five and ten years, and 25% had more than ten years of experience. Respondents represented both public (65%) and private (35%) schools, supporting the breadth of perspectives in the analysis.

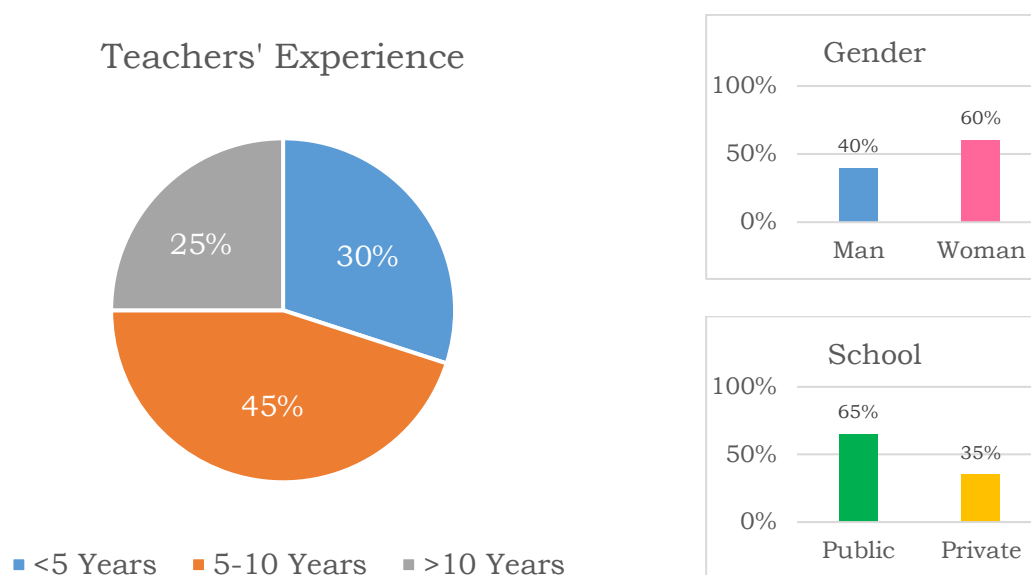


Figure 1. Teacher's Experinece, Gender and School

a. Respondent Characteristics

The demographic characteristics of the respondents demonstrate a level of diversity that is reasonably representative of the elementary school teacher population in Lampung Province. The majority of respondents were female (60%), while male teachers accounted for 40%, reflecting the general gender distribution of elementary school teachers in Indonesia. In terms of school type, 65% of respondents were from public schools and 35% from private schools, allowing the findings to represent the dynamics and challenges faced by teachers in both institutional contexts.

Regarding teaching experience, the distribution was relatively balanced: 30% of teachers had less than five years of experience, 45% had between five and ten years, and 25% had more than ten years of experience. This composition reflects a combination of early-career teachers, who tend to be more adaptable to instructional innovation, and experienced teachers, who possess a deeper understanding of students' needs and the practical challenges of classroom implementation. Most participating teachers had prior experience in developing or using science teaching modules, either independently or collaboratively, thereby providing a valid basis for evaluating their perceptions of interactive deep learning–STEM-PBL modules.

The distribution of respondent characteristics further strengthens the external validity of this study, as the findings do not reflect a single subgroup but rather represent teachers from diverse backgrounds and levels of experience. Consequently, the results may serve as a foundation for the formulation of teacher training programs, the development of innovative teaching modules, and the design of educational policies that are more responsive to the real needs of elementary schools. Moreover, respondent diversity enables a deeper analysis of differences in teachers' perceptions, readiness, and challenges in developing interactive teaching modules, thereby allowing for more contextual and applicable recommendations.

Table 2. Respondent Characteristics

Caractheristic	Category	Total	Percentage (%)
Gender	Woman	60	60
	Man	40	40
School Type	Public	65	65
	Private	35	35

Teaching Experience	<5 years	30	30
	5–10 years	45	45
	>10 years	25	25

The diversity of respondent characteristics serves as an essential foundation for the development of interactive teaching modules that are not only substantively relevant but also adaptive to the real needs and contextual conditions of elementary school teachers across Lampung Province.

b. Teachers' Perceptions of Interactive Deep Learning–STEM-PBL Modules

The majority of teachers (85%) demonstrated positive perceptions toward the use of interactive teaching modules based on deep learning–STEM-PBL. Teachers perceived that these modules effectively enhanced student engagement and understanding, as well as supported the achievement of learning objectives in Integrated Science and Social Studies (IPAS). However, only 38% of teachers reported that the modules they used had fully integrated the three core components of deep learning, namely meaningful, mindful, and joyful learning.

Teachers reported that integrating these components simultaneously within a single module remains a significant challenge. Several teachers expressed the need for concrete examples and practical training to connect all STEM elements within a single learning theme effectively. One of the teachers said, “I would really like to develop modules that are meaningful and enjoyable, but I often feel confused about how to connect all STEM elements within one theme. If there were examples or training, it would certainly be easier.” (Elementary School Teacher, Bandar Lampung)

c. Teachers' Readiness for STEM-PBL Implementation

Teachers' readiness to implement the STEM-PBL approach varied considerably. Only 40% of teachers reported being ready to implement the approach independently, including 15% classified as “very ready” and 25% as “ready,” while the majority (59%) fell into the “moderately ready” category. Teachers in the higher readiness categories were predominantly those who had participated in relevant training or workshops. Teachers with more than ten years of teaching experience tended to demonstrate higher readiness than those with less than five years of experience.

Table 3. Distribution of Teachers' Readiness

Readiness Category	Number of Teachers	Percentage (%)
Very Ready (frequently attending training and experienced)	15	15%
Ready (attended several training sessions)	25	25%
Moderately Ready (understands basic concepts but has not fully implemented them)	30	30%
Less Ready (not accustomed and has limited training)	20	20%
Not Ready (has never been exposed to the concept)	10	10%
Total	100	100%

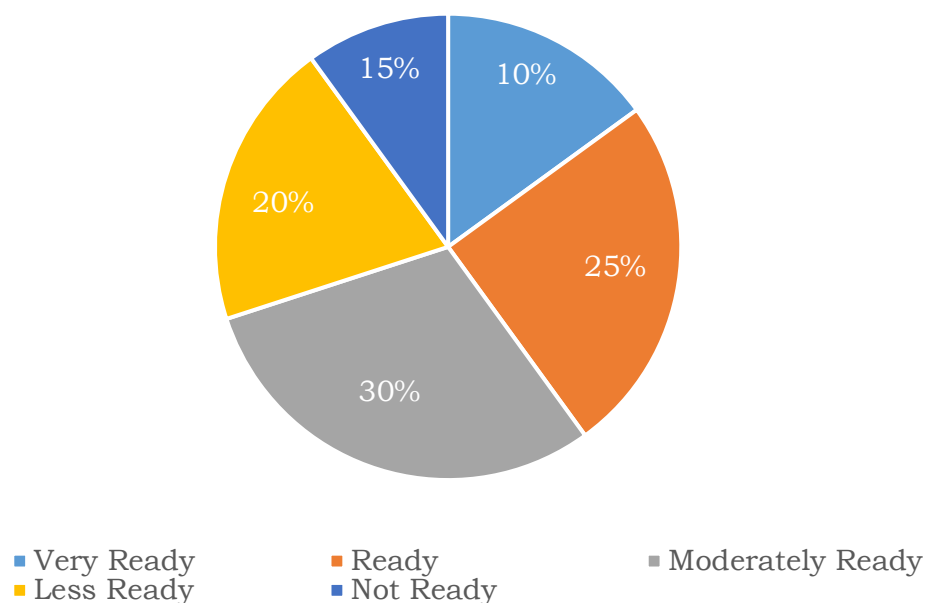


Figure 2. Teachers' Readiness

d. Barriers to Interactive Module Development

Elementary school teachers in Lampung Province identified several significant barriers to developing interactive deep learning–STEM–PBL modules. Survey results revealed that 70% of teachers had never participated in specialized training on interactive module development, resulting in a limited understanding of innovative instructional design and effective integration of educational technology. Additionally, 65% of teachers reported difficulties in developing innovative teaching materials due to heavy administrative workloads and high teaching hours, which significantly reduced the time available for creative work and research on module development.

Furthermore, 60% of teachers indicated difficulties in finding relevant and standardized module references for the elementary school level, particularly those that explicitly integrate deep learning, STEM, and PBL principles. These challenges were exacerbated by limited school support (40%), including inadequate facilities, policies, and incentives, as well as inadequate infrastructure (35%), such as insufficient technological devices, internet access, and digital learning resources.

Table 4. Barriers Faced by Teachers in Developing Interactive Modules

Challenges	Number of Teachers Experiencing	Percentage (%)
Never attended module development training	70	70%
Administrative workload and high teaching hours	65	65%
Limited references for relevant teaching modules	60	60%
Lack of school support	40	40%
Limited learning facilities	35	35%

In addition to these barriers, teachers also faced challenges related to the technical skills required to develop engaging and interactive digital content. Many teachers lacked familiarity with e-learning platforms, instructional design applications, and multimedia tools that could enhance the quality of their modules. The lack of professional learning communities and discussion forums further limited opportunities for teachers to obtain feedback and share best practices with peers.

Another emerging challenge involved adapting modules to accommodate diverse student characteristics and the rapid development of educational technology. Teachers require additional time and creativity to ensure that the modules developed can address diverse learning styles while remaining relevant to students' needs in the digital era.

2. Discussion

This study provides an integrated understanding of elementary teachers' readiness to implement interactive Deep Learning–STEM–PBL modules by revealing a clear perception–practice gap. The findings indicate a discrepancy between teachers' positive perceptions of innovative learning and the quality of instructional modules used in practice. This finding confirms that favorable attitudes alone are insufficient to drive pedagogical transformation, particularly when instructional innovation requires complex interdisciplinary integration and advanced pedagogical design skills. Similar patterns have been reported in international studies, which emphasize that teachers' beliefs must be supported by adequate competence and systemic conditions to result in meaningful instructional change (Darling-Hammond et al., 2019; Estapa & Tank, 2017).

The findings indicate that teacher readiness is a multidimensional construct, extending beyond motivation or teaching willingness alone. As illustrated in the proposed *Teacher Readiness Framework for Deep Learning–STEM–PBL*, readiness encompasses pedagogical competence, instructional design skills, an understanding of deep learning principles, and experience with integrating interdisciplinary STEM approaches. This perspective aligns with English (2016) and Honey et al. (2014), who argue that effective STEM integration requires teachers to simultaneously master content knowledge, pedagogical strategies, and cross-disciplinary coordination. The present study extends this literature by empirically demonstrating how partial readiness across these dimensions contributes to fragmented implementation at the elementary level.

To synthesize the relationships between teachers' perceptions, readiness dimensions, structural conditions, and instructional practices identified in this study, a conceptual Teacher Readiness Framework for Deep Learning–STEM–PBL is proposed (Figure 2).

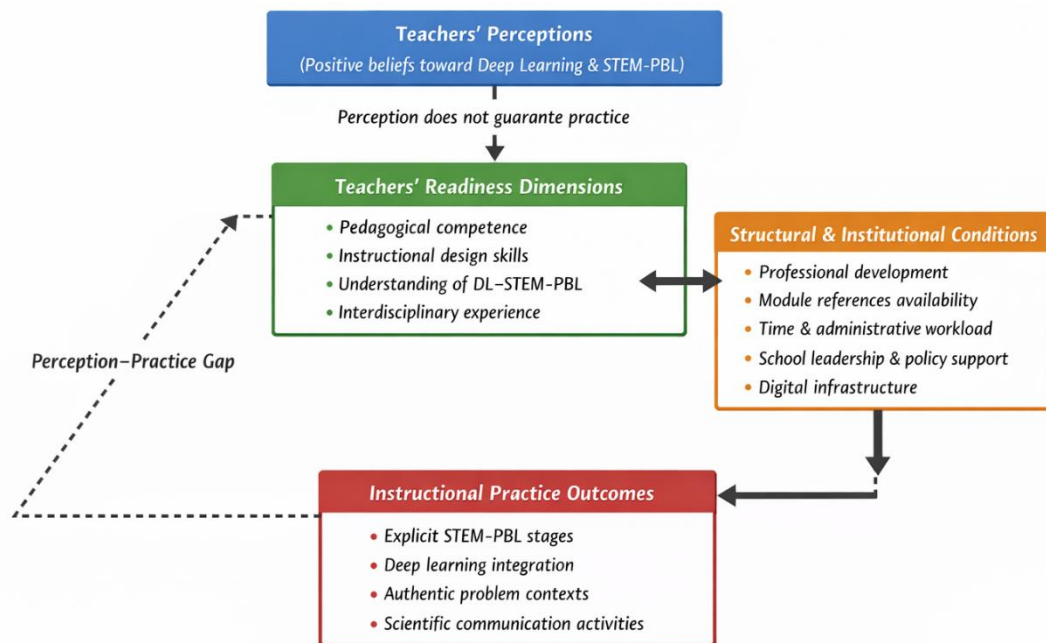


Figure 3. A conceptual framework of elementary teachers' readiness for implementing Deep Learning–STEM-PBL modules.

A key contribution of this study lies in its triangulated methodological approach, which enabled the identification of discrepancies between perceived readiness and actual instructional practice. While survey data indicated relatively high levels of perceived readiness, document analysis revealed that most teaching modules remained procedural and content-oriented, with limited emphasis on authentic problem contexts, explicit STEM-PBL stages, and scientific communication activities. This finding corroborates [Hmelo-Silver \(2023\)](#), who highlights that problem-based and inquiry-oriented learning is often reduced to surface-level activities when teachers lack sufficient instructional design support. By integrating survey, document, and interview data, this study offers a more nuanced understanding of teacher readiness than would be captured through self-reported measures alone.

Structural and institutional conditions emerged as critical factors influencing both teachers' readiness and instructional practices. The findings point to several key barriers, including limited professional development opportunities, high administrative workloads, insufficient module references, and inadequate school support. These challenges are consistent with previous studies conducted in both developed and developing contexts, which emphasize that instructional innovation is highly dependent on systemic support and organizational conditions ([Estapa & Tank, 2017](#); [Zainil et al., 2024](#)). In the context of the Merdeka Curriculum, which emphasizes meaningful and contextual learning, the absence of sustained institutional support may hinder teachers' ability to translate curriculum ideals into classroom realities ([Sulistiani & Dewi, 2024](#)).

From a theoretical perspective, the proposed readiness framework contributes to the growing body of literature on STEM education by shifting the focus from isolated variables toward a holistic readiness perspective. Rather than treating perception, competence, and institutional support as separate factors, the framework highlights their dynamic interaction in shaping instructional outcomes. This approach complements previous models of teacher readiness and professional development ([Darling-Hammond et al., 2019](#); [Maghfiroh & Mahmudah, 2025](#)), while offering a

more context-sensitive explanation of why innovative instructional approaches often fail to achieve their intended impact in practice.

Practically, the findings suggest that efforts to promote the implementation of Deep Learning–STEM–PBL should shift from short-term technical training to prioritizing sustained capacity-building models. Providing teachers with access to validated interactive module exemplars, collaborative professional learning communities, and structured mentoring programs may help bridge the perception–practice gap identified in this study (Brennan & Gorman, 2023; Sholehati et al., 2025). At the policy level, reducing administrative burdens and strengthening institutional incentives for instructional innovation are essential to ensure that teachers have both the capacity and opportunity to engage in high-quality module development.

While grounded in the Indonesian elementary education context, the challenges identified in this study are comparable to those reported in other developing and transitional education systems. Therefore, the proposed *Teacher Readiness Framework for Deep Learning–STEM–PBL* may serve as a transferable analytical lens for future research examining teacher readiness and instructional innovation across diverse educational settings.

Conclusion

The findings reveal a notable discrepancy between teachers' positive perceptions of Deep Learning–STEM–PBL modules and their actual instructional implementation. The perception–practice gap reflects the multidimensional nature of teachers' readiness, particularly in terms of pedagogical competence, instructional design skills, and experience with interdisciplinary STEM integration, as well as structural and institutional constraints such as limited professional development opportunities, high administrative workloads, and insufficient instructional support.

Building on these findings, this study proposes a Teacher Readiness Framework for Deep Learning–STEM–PBL, which conceptualizes readiness as the interaction between teachers' perceptions, core pedagogical capacities, and enabling institutional conditions that collectively influence instructional practice outcomes. While situated in the Indonesian elementary education context, the challenges identified reflect conditions common to developing and transitional education systems, suggesting that the proposed framework has broader relevance for informing teacher professional development, instructional design, and policy initiatives aimed at strengthening STEM–PBL implementation in elementary education.

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