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Exploring Teacher's Perceptions as a Basis for Developing Deep Learning–Based Digital Assessment in Chemistry

Fershi Adi Saputra, Nahadi*, Wawan Wahyu
Chemistry Education, University Pendidikan Indonesia, Bandung, 40154, Indonesia

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* *Corresponding author:*
E-mail: nahadi@upi.edu

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A B S T R A C T

The main challenge in 21st-century chemistry learning lies in the limited availability of assessment instruments that effectively measure students' critical thinking skills in accordance with deep learning principles, namely meaningful, mindful, and joyful learning. In practice, teachers still predominantly employ conventional assessment methods that do not fully support technology-based learning or the development of higher-order thinking skills. As a preliminary study to support the development of deep learning–based digital assessment, this research aims to explore teachers' perceptions and needs regarding the implementation of digital assessment in chemistry learning. A descriptive qualitative approach was employed, involving three senior high school chemistry teachers selected through purposive sampling. Data were collected through semi-structured interviews and analyzed using thematic analysis. The findings indicate that teachers possess a sound pedagogical understanding of deep learning concepts; however, current assessment practices have not yet adequately captured the dimensions of meaningful, mindful, and joyful learning. Teachers expressed positive perceptions toward digital assessment as a means to enhance effectiveness and student engagement, despite challenges related to technological infrastructure and digital literacy. These findings provide an empirical basis for developing deep learning–based digital assessment instruments to strengthen students' critical thinking skills and improve the quality of chemistry learning.

1. Introduction

Education in the digital era is undergoing a significant transformation that demands smart, contextual, and sustainable adaptation, Giovanny & Istanto, (2026). The digitalization of learning should be accompanied by the digitalization of assessment, requiring teachers to implement digital assessment to evaluat students' learning performance. However, Ardiana et al., (2021) many teachers still rely on conventional paper-based assessment systems for formative and summative purposes, which limits assessment effectiveness and does not fully support technology-based learning

In the 21st century, students must possess creative, critical thinking, and problem-solving skills, along with higher-order thinking to meet global demands effectively (Firmansyah et al., 2020; Juita et al., 2025). Eliaumra et al., (2023) Learning extends beyond knowledge acquisition toward the application of skills in real-life contexts. Among these competencies, critical thinking plays a central role and can be cultivated through assessments that stimulate reasoning, reflection, and problem-solving (Hasan et al., 2020; Sholihah & Lastariwati, 2020). However Nugroho & Airlanda (2020) , commonly used tests tend to elicit short answers and do not encourage students to develop critical thinking. Therefore, assessment is a crucial component of the educational process, as improving educational quality requires enhancement of both instructional and assessment (Kristiani et al., 2017; Meng, 2023)

From a theoretical perspective, assessment plays a strategic role in shaping students' thinking patterns. Assessments that emphasize higher-order cognitive processes encourage students to analyze, evaluate, and construct arguments, thereby fostering critical thinking skills. Hasan et al., (2020) Conversely, recall-oriented assessments reinforce surface learning and limit students' opportunities to engage in deep cognitive processing. Therefore, aligning assessment design with 21st-century learning is essential to ensure coherence between learning and evaluation processes.

In science education, particularly chemistry, learning and assessment practices often emphasize lower-order thinking skills. Hasan et al., (2020) Students are frequently directed toward memorization rather than constructing explanations or applying chemical concepts to real-life problems. Wijaya et al., (2017) Empirical evidence indicates that existing assessment instruments have not adequately measured students' critical thinking skills, as most items remain recall-oriented and lack contextual relevance, limiting students' ability to apply chemical knowledge in everyday life. This condition highlights the need for assessment approaches aligned with higher-order thinking objectives.

Chemistry learning presents unique challenges due to its abstract nature, symbolic representations, and the need for multilevel reasoning that connects macroscopic, submicroscopic, and symbolic levels. These characteristics require assessment instruments capable of capturing students' conceptual understanding, analytical reasoning, and ability to transfer knowledge across contexts. However, conventional assessment formats often fail to accommodate these complexities, resulting in a mismatch between the nature of chemistry learning and the assessment methods employed (Mashudi, 2021; Wijaya et al., 2017)

The integration of digital assessment offers significant potential to address these challenges. Digital assessment enables interactive tasks, contextual problem scenarios, immediate feedback, and documentation of students' learning progress.

Previous studies reported that it improve efficiency, enhance engagement, and provide richer information about students' cognitive processes compared to conventional assessments (Ardiana et al., 2021; Eliaumra et al., 2023). Nevertheless, its implementation in chemistry education remains uneven, often constrained by limited infrastructure, teachers' digital literacy, and the absence of instruments aligned with contemporary pedagogical approaches.

In relation to the deep learning paradigm, assessment should function not only as a tool for measuring learning outcomes but also as an integral part of the learning process that promotes meaningful, mindful, and joyful learning. Such assessments are expected to stimulate reflective thinking, encourage self-awareness, and foster positive emotional engagement (Gunartha et al., 2025; Mu'ti, 2025). However, teachers often face difficulties in translating these principles into concrete assessment practices, particularly in digital contexts. This gap highlights the importance of understanding teachers' perceptions and needs as a foundation for developing deep learning–based digital assessment instruments.

To address these challenges, the Ministry of Primary and Secondary Education of Indonesia introduced the *deep learning* paradigm at the end of 2024 as a strategic effort to improve educational quality. Gunartha et al., (2025) This paradigm emphasizes meaningful, mindful, and joyful learning by engaging students in critical analysis, connecting new knowledge with prior understanding, and applying learning in authentic contexts. Mu'ti (2025) , In an era of rapid change, deep learning is considered a relevant approach for fostering adaptive and critical thinking skills. However, many teachers still face difficulties in implementing assessments comprehensively support and measure critical thinking within this framework.

Deep learning enables students to connect prior knowledge with new information, construct knowledge frameworks, and develop critical and reflective thinking alongside active learning behaviors (Levin, 2024; Long et al., 2025). Teachers play a central role in determining the effectiveness of assessment practices, particularly in integrating digital assessment and deep learning approaches. As key decision-makers, teachers' perceptions, beliefs, and readiness influence how assessment is designed and implemented. Challenges in adopting digital assessment are related not only to infrastructure but also to teachers' digital competence and pedagogical readiness (Risdayanti et al., 2025; Tiara & Friyatmi, 2025). In the context of deep learning, teachers' understanding is crucial, as this approach requires alignment between pedagogy, assessment, and learning objectives (Gunartha et al., 2025; Masuku, 2021)

Understanding teachers' perceptions is a critical step in educational innovation, as they act as key agents in translating curriculum policies into classroom practices. Their beliefs, experiences, and readiness influence the adoption of new assessment approaches. Research by Kürşat et al., (2025) indicates that the application of artificial intelligence and digital assessment has increased rapidly; however, assessments that truly measure deep learning remain limited. Risdayanti et al.,(2025) Furthermore, innovations are more effective when developed based on teachers' needs and contextual constraints

Based on these conditions, a gap remains between the expectations of deep learning–oriented instruction and the availability of appropriate digital assessment instruments, particularly in chemistry education. As an initial step, *"this study aims to explore teachers' perceptions, understanding, and needs regarding the application of deep learning and digital assessment*". This study is expected to provide a conceptual and empirical foundation for developing deep learning–based digital assessment instruments capable of strengthening students' critical thinking skills in school.

2. Methodology

This study employed a qualitative approach with a descriptive method. However Sugiono (2013) the qualitative research approach is particularly appropriate when the researcher seeks to gain an in-depth understanding of a complex and meaningful social phenomenon This approach was chosen because the main objective of the study was to obtain a comprehensive understanding of teachers' perceptions, understanding, and needs regarding the development of a digital assessment based on *deep learning* in chemistry learning. Since qualitative research is often referred to as a *naturalistic method* because it is conducted in natural settings this approach allowed the researcher to explore educational phenomena from the participants' perspectives in a natural and contextual manner rather than through numerical or statistical data.

Through the descriptive method, the researcher aimed to present a detailed depiction of the realities observed in the field without intervening in the ongoing conditions. This approach was deemed most suitable for a preliminary study, as it was not intended to test hypotheses but rather to explore teachers' views on assessment practices and *deep learning* implementation. The research design also enabled the identification of challenges, needs, and opportunities for digital assessment innovation in secondary chemistry education. The study was conducted systematically, beginning with the development of interview instruments, the execution of teacher interviews, and the thematic data analysis. This approach was expected to provide a solid empirical foundation for subsequent research phases focused on developing a digital assessment product.

The participants of this study consisted of three high school chemistry teachers selected through *purposive sampling*. This technique was used because the researcher required participants who were knowledgeable and experienced in implementing chemistry learning and assessment at the secondary education level. The criteria for selecting participants were as follows: (1) active teachers currently teaching chemistry at the senior high school level, (2) having a minimum of one year of teaching experience, and (3) having implemented or being familiar with digital-based assessments and deep learning-oriented instruction. The three participants came from different schools in Bandung, consisting of one public and two private institutions implementing the *Merdeka Curriculum*. This diversity provided a broader perspective regarding various teaching contexts and school resources. Prior to the interviews, the researcher explained the purpose of the study and obtained informed consent from all participants. To ensure confidentiality, participants' identities were anonymized using the codes *Teacher 1*, *Teacher 2*, and *Teacher 3* throughout the research report.

Instruments

The primary instrument used in this study was a semi-structured interview guide. The instrument was developed based on the theoretical framework of *deep learning*, which includes three main dimensions: *meaningful learning*, *mindful learning*, and *joyful learning*. Each dimension was elaborated into several indicators that served as the basis for constructing interview questions. For instance, within the dimension of *meaningful learning*, a sample question was: "What kind of instrument do you use to assess whether students truly understand the concept (*meaningful learning*)?" The *mindful learning* dimension focused on students' reflective awareness during the learning process, while the *joyful learning* dimension addressed how teachers create enjoyable and interactive classroom experiences.

Data Collection

Before implementation, the interview guide was validated through expert judgment involving assessment and learning specialists to ensure its relevance and alignment with the study's objectives. Interviews were conducted in person and online, lasting approximately 30–45 minutes per participant. All sessions were audio-recorded using digital devices to preserve data accuracy and subsequently transcribed verbatim. To enhance data credibility, the researcher performed *member checking* by confirming the transcriptions with each participant to avoid misinterpretation. To ensure the trustworthiness of the research data, this study applied four criteria: credibility, transferability, dependability, and confirmability. Credibility was ensured through member checking, in which interview transcripts and summaries were confirmed by each participant to verify the accuracy of interpretations.Transferability was addressed by providing detailed descriptions of the research context and participant characteristics, enabling readers to assess the applicability of the findings to similar contexts. Dependability was ensured by documenting the research process systematically, including data collection and analysis procedures. Confirmability was strengthened through peer debriefing with supervisors or academic colleagues to minimize researcher bias in data interpretation.

This study adhered to ethical principles in educational research. Prior to data collection, the researcher explained the objectives, benefits, and procedures of the study to all participants. Informed consent was obtained from each participant, and participation was entirely voluntary, with participants retaining the right to withdraw at any time without penalty. Participants' identities were kept confidential by using coded identifiers (Teacher 1, Teacher 2, and Teacher 3) throughout the research report. All data were used solely for academic purposes and were securely stored by the researcher.

Data Analysis

The data were analyzed using *thematic analysis*, following the six-phase procedure proposed by Braun & Clarke, (2006). The first phase, *familiarizing yourself with the data*, involved rereading all interview transcripts multiple times to gain a comprehensive understanding of the context and meaning of the data. The second phase, *generating initial codes*, required the researcher to identify and highlight key portions of the data relevant to the research focus, such as teachers' perceptions of *deep learning* or challenges in implementing digital assessments. The third phase, *searching for themes*, involved categorizing similar codes into broader themes, such as "teachers' pedagogical understanding," "conventional assessment practices," "technological barriers," and "potential for digital assessment."

In the fourth phase, *reviewing themes*, the researcher revisited the identified themes to ensure their coherence with the raw data and to avoid excessive generalization. The fifth phase, *defining and naming themes*, focused on formulating clear operational definitions and names for each theme to facilitate interpretation. The final phase, *producing the report*, involved compiling the analysis into a narrative description that illustrated teachers' perspectives on *deep learning*-based assessment.To ensure the validity and trustworthiness of the data, the researcher applied *source triangulation* by comparing findings across participants, as well as *peer debriefing* with academic supervisors to minimize potential researcher bias. The analytical process was conducted concurrently with data collection until consistent and stable thematic patterns were identified.

3. Results and Discussion

Result

This section presents the main findings of the study derived from thematic analysis of semi-structured interviews with three senior high school chemistry teachers. The results describe teachers' perceptions, experiences, and needs regarding digital assessment based on deep learning as presented in Table 1

Table 1. Thematic Findings of Teachers' Perceptions on Digital Assessment Based on Deep Learning

Main Findings	**Thematic Descriptions**
Teachers' pedagogical understanding of deep learning	Teachers understand *deep learning* as meaningful, mindful, and joyful learning that encourages active engagement and reflective thinking..
Limited implementation of digital assessment	Teachers still rely on conventional assessment methods. The main challenges include limited time, inadequate technological infrastructure, and varying levels of digital literacy.

Main Findings	Thematic Descriptions
Positive perceptions toward deep learning-based digital assessment	Teachers perceive digital assessment as a potential tool to enhance evaluation effectiveness and student motivation through interactive platforms

Teachers' Pedagogical Understanding of Deep Learning

The findings indicate that all participating teachers demonstrated a pedagogical understanding of deep learning as a learning approach that emphasizes meaningful understanding, students' self-awareness, and enjoyable learning experiences. This is reflected in one teacher's statement that *"deep learning emphasizes meaningful learning, and the three pillars—mindful, meaningful, and joyful learning—complement each other"* (Teacher 1). Teachers conceptualized deep learning not merely as content mastery, but as a process that enables students to actively construct knowledge, reflect on their learning processes, and engage emotionally in learning activities as noted by Teacher 2, *"deep learning is an approach that brings learning closer to students, where they should experience the three pillars (mindfull, meaningfull, and joyfull) in the learning process."* This understanding reflects teachers' awareness of the shift from traditional, teacher-centered instruction toward student-centered learning aligned with 21st-century educational demands.

Teachers emphasized that meaningful learning in chemistry occurs when students are able to relate abstract chemical concepts to everyday phenomena, This is reflected in Teacher 2's statement that *"learning should be connected to students' daily experiences so that they can better understand the concepts."* Given the abstract and multirepresentational nature of chemistry, this perspective is particularly important. Chemistry concepts often require students to connect macroscopic observations, submicroscopic explanations, and symbolic representations. Teachers' recognition of meaningful learning therefore suggests an understanding that chemistry learning should support conceptual integration rather than rote memorization of formulas and procedures.

Mindful learning was described by teachers as students' awareness of their own learning processes, as noted by Teacher 2*, "students should be aware of how they learn and understand why they arrive at certain answers."* including how they arrive at answers and why certain concepts are applicable in specific contexts. However, teachers also acknowledged that fostering mindful learning remains challenging, particularly when assessment practices do not explicitly encourage reflection or reasoning. This finding indicates that while teachers conceptually value reflective thinking, the lack of appropriate assessment instruments limits the realization of mindful learning in classroom practice.

Joyful learning, according to teachers, was associated with students' active participation, positive emotional engagement, and reduced anxiety during learning and assessment. This is supported by Teacher 3, who stated that "*deep learning is important because it encourages students to be more active and makes learning more relevant to everyday life."* Teachers perceived that enjoyable learning experiences can increase students' motivation and willingness to engage with challenging chemistry concepts. Overall, teachers' pedagogical understanding of deep learning demonstrates cognitive readiness to implement innovative instructional and assessment practices, although such readiness has not yet been fully supported by existing assessment systems.

Current Implementation of Digital Assessment in Chemistry Learning

Despite teachers' conceptual understanding of deep learning, the implementation of assessment practices aligned with its principles was found to be limited. Teachers reported that they predominantly employed conventional assessment methods, For example, one teacher stated that *"assessment is still mostly conventional" (Teacher 1)* such as paper-based tests and objective questions, to evaluate student learning outcomes. These assessment practices primarily focus on measuring factual knowledge and procedural skills, rather than students' reasoning processes, reflective thinking, or conceptual understanding as stated by Teacher 1, *"most assessments are still focused on factual knowledge rather than deeper understanding."* Several constraints were identified as influencing teachers' reliance on traditional assessment methods. Time limitations were frequently mentioned as a major barrier, this is reflected in Teacher 2's statement that *"limited time becomes a major obstacle in implementing digital assessment"* particularly in relation to designing open-ended or performance-based assessment tasks that align with deep learning principles. Furthermore, limited technological infrastructure and unequal access to digital devices limited teachers' ability to implement digital assessments consistently across classes, as Teacher 1 stated that *"infrastructure is one of the main constraints in implementing digital assessments."*

Teachers' varying levels of digital literacy also emerged as a significant challenge, this is supported by Teacher 2, who mentioned that *"I am familiar with basic digital tools, but I am still unsure how to design assessments that measure higher-order thinking skills."* Although some teachers are familiar with basic digital platforms, they expressed uncertainty in designing digital assessments that can effectively measure higher-order thinking skills, as time constraints often limit their implementation. As stated by Teacher 3, "*assessment is sometimes still conducted conventionally due to limited time."* These challenges collectively contribute to teachers' decisions to maintain conventional assessment practices, even when they recognize their limitations. This finding highlights that, although teachers conceptually support deep learning, assessment practices remain constrained by contextual and technical factors. As a result, assessment has not yet functioned as a tool to reinforce deep learning principles in chemistry instruction.

Teachers' Perceptions Toward Deep Learning–Based Digital Assessment

Despite the identified challenges, all participating teachers expressed positive perceptions toward the integration of deep learning–based digital assessment. As stated by one teacher, *"digital assessment is very good to be applied in schools because it makes it easier for teachers to assess students"* (Teacher 1). Teachers viewed digital assessment as a promising strategy to improve assessment effectiveness, Teacher 1 further emphasized that *"digital assessment helps make the evaluation process more efficient and organized "* particularly in terms of efficiency, documentation, and student engagement. Digital assessment was perceived as offering greater flexibility in presenting assessment tasks and collecting student responses. However, Teacher 2 noted that *"digital assessment is good and applicable, but its implementation should be gradual,"* indicating that it cannot be implemented simultaneously without considering its progressive success.

Teachers also mentioned digital platforms such as Google Classroom, Quizizz, and Canva as tools that can support interactive and visually engaging assessment practices. These platforms were considered capable of reducing students' anxiety As noted by Teacher 3, *"students feel more relaxed when using digital platforms compared to traditional tests"* during assessment and increasing motivation through interactive features. In addition, teachers highlighted that digital assessment facilitates timely feedback, This indicates that digital assessment supports more responsive and effective feedback in the learning process as stated by Teacher 3, *"digital assessment is faster through the use of technology and makes the teacher's work easier,"* which is essential for supporting students' learning processes and encouraging reflection.

Importantly, teachers perceived digital assessment not only as a technological innovation but also as a potential pedagogical tool aligned with deep learning principles. When designed appropriately, digital assessment is believed to support meaningful learning through contextual tasks, mindful learning through reflective questions, and joyful learning through engaging and interactive formats. However, teachers emphasized that this potential can only be realized if digital assessment instruments are systematically designed and supported by adequate training and infrastructure. Overall, teachers' positive perceptions toward deep learning–based digital assessment indicate openness to assessment innovation. These findings suggest that future efforts should focus on providing practical assessment models and professional development that enable teachers to translate their positive attitudes and pedagogical understanding into effective classroom assessment practices.

Elaboration of Findings Based on Deep Learning Dimensions

To provide a more detailed description of the results, teachers' perceptions and assessment practices were further elaborated according to the three dimensions of deep learning, namely meaningful learning, mindful learning, and joyful learning. This elaboration aims to clarify how each dimension is reflected in current assessment practices and to identify existing gaps in the implementation of deep learning–oriented digital assessment in chemistry learning as presented in Table 2.

Table 2. Teachers' Assessment Practices Based on Deep Learning Dimensions

Deep Learning Dimension	**Teachers' Descriptions of Current Practices**	**Identified Gaps in Assessment Implementation**
Meaningfull Learning	Teachers emphasized that assessment should measure students' conceptual understanding beyond memorization and support the application of chemistry concepts in real-life contexts.	Assessment tasks are still dominated by recall-based questions and lack authentic, contextual problem situations.
Minddfull Learning	Teachers recognized the importance of students' awareness and reflection during learning; however, assessments mainly focus on final answers rather than students' reasoning processes.	Reflective thinking and metacognitive processes are not explicitly assessed due to limited time and lack of suitable assessment instruments
Joyfull Learning	Teachers perceived digital assessment as having the potential to create engaging and enjoyable assessment experiences through interactive digital platforms	Digital assessments are not yet systematically designed to support joyful learning and are implemented only occasionally

Discussion

This study aimed to explore teachers' perceptions and needs related to the application of deep learning and digital assessment in chemistry education. The findings indicate that teachers possess a conceptual and pedagogical understanding of deep learning as meaningful, mindful, and joyful learning. This understanding suggests that teachers are cognitively prepared to adopt instructional approaches aligned with 21st-century learning demands. These findings are consistent with Mashudi, (2021) who emphasized that learning designed for the 21st century should enable students to apply knowledge and skills across diverse contexts and problem situations. Teachers' understanding of deep learning therefore provides an important foundation for developing assessment practices that evaluate not only learning outcomes but also students' cognitive processes during learning.

However, the limited implementation of deep learning-oriented digital assessment reflects a gap between pedagogical understanding and classroom practice. Teachers' reliance on conventional assessment methods is influenced by practical constraints, including time limitations, insufficient technological infrastructure, and varying levels of digital literacy. Similar challenges were reported by Tiara and Friyatmi (2025) who found that paper-based assessments remain dominant in classroom practice, particularly in formative and summative evaluation. Despite these challenges, teachers' positive perceptions toward digital assessment highlight its potential as an effective assessment strategy. Digital platforms were perceived as capable of increasing student motivation, facilitating interactive assessment, and providing timely feedback. This finding aligns with with Risdayanti et al., (2025) who argued that digital transformation in education offers opportunities for innovation and the creation of more inclusive and relevant learning environments.

These findings are also consistent with research conducted by Irawan et al., (2025) which indicates that digital assessment is capable of improving assessment efficiency, the accuracy of learning outcomes, and student motivation. Furthermore, a study conducted by Nurani et al., (2025) shows that the developed digital assessment tool is effective in supporting teachers in conducting more efficient evaluations and providing a clearer understanding of students' conceptual understanding. This implementation also enhances graduates' readiness to face the digital workforce. Thus, digital assessment is not only an evaluation tool but also an adaptive strategy for future learning.

Deep Learning and Assessment Alignment in Chemistry Learning

To further understand this gap, the discussion is extended to examine the alignment between deep learning principles and assessment practices in chemistry education. The findings indicate that although teachers possess a sound conceptual understanding of deep learning, this understanding has not yet been fully translated into assessment practices. This condition reflects a common gap between pedagogical knowledge and classroom implementation, particularly in assessment design.In the context of chemistry education, this misalignment becomes more critical due to the abstract and multirepresentational nature of chemical concepts. Assessments that fail to address students' reasoning processes across macroscopic, submicroscopic, and symbolic levels tend to oversimplify learning outcomes and limit opportunities for critical thinking development. As noted by Hasan et al., (2020) assessment instruments emphasizing higher-order thinking are essential for capturing students' analytical and reflective abilities.

Teachers' Readiness and Challenges in Implementing Digital Assessment

Another important finding is teachers' positive perception of digital assessment, despite challenges related to infrastructure, time constraints, and digital literacy. This supports previous studies indicating that teachers generally welcome digital innovation when adequate support and training are provided (Ardiana et al., 2021; Risdayanti et al., 2025). However, the persistence of conventional assessment practices suggests that positive perceptions alone are insufficient to drive pedagogical change. Teachers' readiness is strongly influenced by contextual factors, including school facilities, access to technology, and institutional support. Furthermore, Luthfi et al., (2026) successful implementation requires an equitable technology infrastructure, ongoing teacher professional development, and curriculum alignment . Consequently, professional development programs focusing on digital assessment literacy are essential to bridge the gap between perception and practice.

Implications for the Development of Deep Learning–Based Digital Assessment

The results of this study highlight the importance of grounding the development of digital assessment instruments in teachers' real needs and classroom contexts. As a preliminary study, these findings provide empirical insights for designing deep learning–based digital assessments that are feasible, valid, and aligned with chemistry learning objectives. Moreover, integrating digital assessment with deep learning principles has the potential to transform assessment from a mere evaluative tool into a meaningful learning experience. This perspective aligns with Indonesian education policy emphasizing learning quality over procedural completion (Gunartha et al., 2025; Mu'ti, 2025)

Despite the valuable insights generated, this study has several limitations that should be acknowledged. First, the number of participants involved in this study was limited to three chemistry teachers, which may affect the transferability of the findings to broader educational contexts. While the use of in-depth qualitative data provides rich insights, the small sample size limits the generalization of the results beyond similar contexts.Second, this study relied on self-reported data obtained through semi-structured interviews, which may be subject to potential bias, such as social desirability bias or subjective interpretation. Teachers may have expressed perspectives that reflect ideal practices rather than actual classroom implementation. In addition, the study was conducted within a specific local context, namely Bandung, which may influence teachers' experiences due to particular institutional, cultural, and technological conditions. Therefore, the findings should be interpreted with consideration of these contextual limitations.

Despite these limitations, this study offers a meaningful contribution as a preliminary investigation into the integration of deep learning principles and digital assessment in chemistry education. Unlike previous studies, such as those presented by (Jurāne-Brēmane, 2023; Permatasari et al., 2023) , which primarily focused on the effectiveness of digital assessment tools, this study specifically highlights the gap between teachers' pedagogical understanding of deep learning and their actual assessment practices. This gap represents a critical area for future development. Furthermore, this study contributes to the field by providing an initial empirical foundation for the design of deep learning–based digital assessment instruments that aim to support students' critical thinking skills. By identifying teachers' perceptions, challenges, and needs, this study serves as a basis for developing contextually relevant and pedagogically aligned assessment models in future research.

4. Conclusion

This study aimed to explore teachers' perceptions, understanding, and needs regarding the implementation of deep learning and digital assessment in chemistry learning. The findings reveal that teachers possess a sound conceptual understanding of deep learning as meaningful, mindful, and joyful learning. However, its implementation in assessment practices remains limited due to constraints related to time, technological infrastructure, and teachers' digital literacy. These findings indicate a gap between teachers' pedagogical understanding and their actual assessment practices.

Overall, the study successfully identified teachers' perceptions and needs as well as the key challenges in implementing deep learning–based digital assessment, although the findings also highlight that its practical implementation has not yet been fully achieved. Despite these challenges, teachers demonstrate positive perceptions toward the integration of deep learning–based digital assessment, as it is considered capable of enhancing assessment effectiveness, student engagement, and feedback quality. This suggests that the development of practical and context-appropriate digital assessment instruments is both necessary and feasible. Overall, this study provides a conceptual foundation for the development of digital assessment instruments aimed at strengthening students' critical thinking skills in chemistry learning

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development and implementation of digital assessment instruments grounded in deep learning principles. It is also expected that this research will support efforts to strengthen students' critical thinking skills and contribute to the broader improvement of educational quality in Indonesia.

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