



## Conceptual Framework of an AI-Based Adaptive Formative Assessment to Support Differentiated Elementary Science Learning

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**Abstract:** Formative assessment in elementary science is often homogeneous, limiting its diagnostic role and support for differentiated learning. This study designs a conceptual framework for an AI-based adaptive formative assessment system to support differentiated learning in elementary science. Using R&D with the ADDIE model, the article focuses on the Analysis and Design stages. Analysis identified assessment problems and teachers' needs through semi-structured interviews and a needs questionnaire; design produced system specifications and conceptual designs from empirical findings and theory. Key outputs include: (1) an assessment blueprint with progressive difficulty, (2) adaptive logic driven by student responses, (3) a system flow diagram, and (4) an initial application prototype. It emphasizes diagnostic function, meaningful formative feedback, and teacher usability. Theoretically, it advances formative assessment research by integrating adaptivity within an assessment-for-learning perspective. In practice, the framework can guide developers, schools, and policymakers in enhancing teachers' assessment literacy and implementing adaptive formative assessment in elementary science.

**Abstrak:** Praktik asesmen formatif dalam pembelajaran IPA di sekolah dasar sering bersifat homogen sehingga fungsi diagnostik dan dukungan untuk pembelajaran berdiferensiasi belum optimal. Penelitian ini merancang kerangka konseptual sistem asesmen formatif adaptif berbasis kecerdasan buatan (AI) untuk mendukung pembelajaran IPA yang berdiferensiasi di SD. Pendekatan R&D dengan model ADDIE difokuskan pada tahap Analysis dan Design. Analisis dilakukan melalui identifikasi masalah asesmen dan kajian kebutuhan guru menggunakan wawancara semi-terstruktur serta angket kebutuhan. Tahap desain merumuskan spesifikasi dan rancangan konseptual berdasarkan temuan empiris dan kajian teori. Luaran utama mencakup blueprint asesmen bertingkat, logika adaptivitas berbasis respons siswa, diagram alur sistem adaptif, dan prototipe antarmuka awal. Desain menekankan fungsi diagnostik, penyediaan umpan balik formatif yang bermakna, dan kemudahan penggunaan bagi guru. Secara teoretis, penelitian ini memperkaya kajian assessment-for-learning dengan integrasi adaptivitas; secara praktis, menjadi acuan bagi pengembang, sekolah, dan pembuat kebijakan untuk meningkatkan literasi asesmen guru dan mengimplementasikan asesmen adaptif di SD.

## A. Introduction

Assessment plays a crucial role in supporting meaningful learning in elementary education, particularly in elementary science learning. Assessment should not only serve as a tool to measure learning outcomes but also as a mechanism to guide, monitor, and continuously improve students' learning processes (Earl, 2013). Formative assessment, in particular, is designed to provide ongoing feedback that helps students identify conceptual learning gaps and supports teachers in adjusting instructional strategies according to students' learning needs (Heritage, 2021; Sadler, 2022; Wylie & Lyon, 2021). However, in many elementary classrooms, assessment practices remain dominated by summative approaches that emphasize final scores rather than students' conceptual understanding and learning progression. As a result, the diagnostic and developmental functions of assessment are often underutilized, limiting its potential to support differentiated learning.

In the context of elementary science learning, formative assessment practices are often implemented uniformly without accounting for differences in students' abilities, learning readiness, and the pace of conceptual understanding. Teachers tend to use homogeneous sets of assessment items and provide similar feedback for all students, despite the heterogeneous nature of elementary classrooms. Empirical studies in Indonesian elementary schools indicate that teachers' assessment practices remain dominated by low-level cognitive demands and limited diagnostic feedback, underscoring the need to strengthen teachers' assessment literacy and adaptive assessment practices (Diana & Kartika, 2024). A recent literature review further confirms that differentiated learning approaches in primary education remain underimplemented despite growing recognition of their importance, highlighting the need for adaptive media and assessment tools that can accommodate diverse student learning profiles in elementary classrooms (Zakiyyah et al., 2025).

Based on preliminary observations and reflections on classroom assessment practices, it was identified that elementary science teachers tend to design formative assessment items with similar levels of difficulty and uniform feedback formats. Such practices result in identical assessment experiences for students with diverse learning needs and limit the diagnostic function of formative assessment in mapping students' conceptual understanding. These conditions indicate a practical problem in elementary science classrooms, where assessment has not yet functioned optimally as a tool to support differentiated learning and instructional decision-making.

To confirm and further elaborate on this identified problem, a needs analysis was conducted through teacher interviews and a teacher needs questionnaire. The needs analysis was intended to validate the initial problem identification, explore underlying constraints faced by teachers, such as time limitations, administrative workload, and limited access to adaptive assessment tools, and identify practical requirements for designing an adaptive formative assessment framework. This step ensured that the proposed design was grounded in authentic classroom needs rather than in theoretical assumptions alone.

The importance of strengthening formative assessment practices in elementary science learning is further reinforced by empirical evidence of low science literacy among Indonesian students. Results from the Programme for International Student Assessment (PISA) consistently indicate that Indonesian students' science performance remains below the OECD average, reflecting weaknesses in conceptual understanding and scientific problem-solving skills (OECD, 2019). National assessment reports also show that most elementary students achieve mastery at lower cognitive levels, highlighting the need for assessment approaches that are more diagnostic, adaptive, and supportive of conceptual development (Balitbang Kemendikbud, 2020). Without effective formative assessment tools, teachers struggle to identify learning gaps early and provide timely, targeted instructional interventions (Hattie, 2023; Hattie & Clarke, 2018).

Recent developments in digital technology and Artificial Intelligence (AI) have opened new possibilities for addressing these challenges. AI-based formative assessment systems can analyse student responses in real time, dynamically adjust question difficulty levels, and provide immediate, personalised feedback (Holmes et al., 2019; Luckin et al., 2016). Empirical studies published in the last five to ten years demonstrate that adaptive, technology-based assessments can enhance learning motivation, improve diagnostic accuracy, and strengthen the effectiveness of formative feedback in science learning contexts (Chen et al., 2020; Rasmini et al., 2023; Hopfenbeck et al., 2023). These features align closely with the principles of differentiated instruction and data-driven learning promoted in recent educational reforms.

Despite the growing body of literature on AI-based assessment, a clear research gap remains. Most previous studies have focused on secondary or higher education contexts and have primarily emphasized empirical effectiveness testing or algorithmic performance. Research explicitly addressing the conceptual design of AI-based adaptive formative assessment for elementary science learning remains limited. Moreover, many studies prioritize technological innovation, while the pedagogical integration of formative assessment principles, differentiated learning, and elementary students' developmental characteristics has received relatively little attention at the conceptual level.

This study differs from previous research by proposing a pedagogically grounded conceptual framework for an AI-based adaptive formative assessment system specifically designed for elementary science learning. Rather than focusing on empirical effectiveness or the development of complex machine learning algorithms, this study emphasizes integrating formative assessment theory, adaptive assessment logic, and differentiated learning principles. The novelty of this research lies in its conceptual contribution: a systematic design of an adaptive formative assessment framework that supports the diagnosis of students' conceptual understanding in science and provides formative feedback aligned with the characteristics of elementary learners. This contribution is important because it provides a theoretical foundation to guide the future development and empirical testing of AI-based assessment systems in primary education.

Therefore, this study addresses two main research questions: (1) What assessment-related needs and challenges are experienced by elementary science teachers in implementing formative assessment?. Moreover, (2) How can an Artificial Intelligence (AI)-based adaptive formative assessment system be conceptually designed to support differentiated elementary science learning?. To answer these questions, this study aims to design a pedagogically grounded conceptual framework for an AI-based adaptive formative assessment system. Specifically, the study seeks to: (1) identify teachers' assessment needs and challenges in implementing formative assessment, (2) develop an adaptive assessment framework that integrates AI-driven logic with formative assessment principles, and (3) propose a structured conceptual model that can serve as a reference for future system development and empirical research. The contribution of this study lies in providing a theoretically grounded, pedagogically oriented conceptual design for AI-based adaptive formative assessment that can guide future research and support the development of assessment systems that facilitate differentiated elementary science learning.

## B. Method

This study employed a research and Development (R&D) approach using the ADDIE instructional design model (Branch, 2009), which consists of the stages of *Analysis, Design, Development, Implementation, and Evaluation*. However, this article is explicitly positioned as a design paper and is therefore limited to the Analysis and Design stages only. It does not aim to examine the effectiveness of the proposed system or its impact on student learning outcomes. The development, implementation, and evaluation stages are planned for subsequent research and will be reported in future publications. The primary focus of this study is to produce a pedagogically grounded conceptual framework for an Artificial Intelligence (AI)-based adaptive formative assessment system to support elementary science learning.

The analysis stage began with problem identification related to formative assessment practices in elementary science classrooms. Based on preliminary observations and reflections on classroom assessment practices, it was identified that teachers tend to design homogeneous formative assessment items and provide non-adaptive feedback, despite students' diverse learning abilities and needs. This condition limits the diagnostic function of formative assessment and hinders the implementation of differentiated learning. To confirm and further elaborate on the identified problem, a needs analysis was subsequently conducted.

The participant involved in this study was an elementary science teacher from a public elementary school in Tangerang Selatan, Indonesia. The participant was selected using purposive sampling, based on professional experience in teaching elementary science and active involvement in formative assessment practices. The involvement of a single teacher is methodologically justified because the study was conducted at the analysis stage of design-based research, which prioritizes depth of contextual understanding rather than statistical generalization.

Data were collected through semi-structured interviews, a teacher needs questionnaire, and a literature review. Semi-structured interviews were conducted to explore formative assessment practices, challenges in designing adaptive assessment items, and teachers' expectations regarding the use of AI in formative assessment. The teacher needs a questionnaire that employs a Likert scale from 1 to 4 and consists of statements addressing formative assessment practices, assessment challenges, and expectations for AI-based adaptive assessment features. The questionnaire's measurement aspects are summarised in Table X. In addition, a literature review of recent primary studies published within the last five to ten years, curriculum documents, and assessment guidelines was conducted to strengthen the theoretical foundation and inform the formulation of design principles.

Qualitative data from interviews were analyzed using thematic analysis, including data reduction, categorization, and theme interpretation related to assessment problems and design needs. Quantitative data from the teacher needs questionnaire were analyzed using descriptive statistics to identify trends in teachers' needs and perceptions. The results of both analyses were synthesized to formulate design requirements and specifications that informed the development of the conceptual framework for the AI-based adaptive formative assessment system.

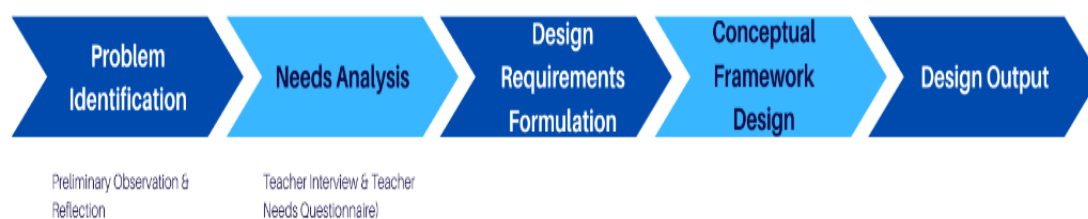
**Table 1.** Teacher Needs Questionnaire (Likert Scale 1–4)

| Aspect Measured                    | Indicator Description   | Scale |
|------------------------------------|---|-------|
| Importance of formative assessment | Perceived importance of formative assessment for monitoring students' understanding | 1–4   |
| Assessment variation needs         | Need for varied and engaging formative assessment items                             | 1–4   |
| Difficulty in item construction    | Challenges in designing items aligned with learning objectives                      | 1–4   |
| Technology support needs           | Need for technological assistance in item development                               | 1–4   |
| Adaptive difficulty features       | Need for multiple difficulty levels (easy–medium–hard)                              | 1–4   |
| Feedback and evaluation            | Need for automated feedback and assessment result analysis                          | 1–4   |
| Ease of use                        | Expectation of ease of use for teachers with limited technological experience       | 1–4   |
| Interest in AI-based assessment    | Willingness to use AI-based assessment tools  | 1–4   |

*jmxfscale description: 1 = Not Appropriate; 2 = Fairly Appropriate; 3 = Appropriate; 4 = Highly Appropriate.*

Table 1 summarises the measurement aspects of the teacher needs questionnaire. At the same time, the overall research procedure is illustrated in Figure X. Overall, the research procedure was structured systematically, beginning with problem identification, followed by needs analysis, formulation of design requirements, conceptual framework design, and

culminating in the design output. The complete research flow from the initial analysis to the final design stage is presented in Figure 1.



**Figure 1.** The research Procedure

As illustrated in Figure 1, the research procedure was systematically conducted from problem identification to the development of the conceptual design, ensuring coherence between the analysis and design stages of the study.

### C. Result

The result of this study is a conceptual design consisting of an Artificial Intelligence (AI)-based adaptive formative assessment framework for elementary science learning. In line with this article's positioning as a design paper, the results are presented as outcomes of the Analysis and Design stages, including the identification of assessment problems, the teacher needs analysis, and the synthesis of the system design prior to expert validation and implementation.

The analysis stage identified major problems in formative assessment practices in elementary science classrooms. Teachers predominantly employed homogeneous formative assessment items of similar difficulty and provided uniform feedback to all students, regardless of differences in learning ability and progress. As a result, formative assessment had not yet functioned optimally as a diagnostic tool to support differentiated instruction and informed instructional decision-making.

These initial findings were further confirmed through a needs analysis conducted using semi-structured interviews and a teacher needs questionnaire. The interview results indicated that teachers experienced difficulties in developing varied formative assessment items due to limited instructional time, administrative workload, and the absence of tools that support adaptive assessment design. Teachers also expressed a need for assistance in generating assessment items with varying difficulty levels and in providing formative feedback that reflects students' learning progress.

The results of the teacher needs questionnaire reinforced these findings. Teacher responses indicated a very high level of need for an AI-based adaptive formative assessment system. Quantitatively, the need for variation and adaptivity of assessment item difficulty received a score of 4.00 (on a 1–4 Likert scale), the need for meaningful formative feedback received a score of 4.00, and the need for technological support to accelerate the development of assessment items also received a score of 4.00. In addition, the need for ease of system use by teachers received a score of 4.00, indicating that practicality and usability are critical

considerations for the adoption of AI-based assessment systems in elementary schools. These scores fall within the “highly appropriate” category, suggesting that existing formative assessment practices are not yet fully aligned with the demands of differentiated elementary science learning.

Based on the results of problem identification and needs analysis, several key design requirements were formulated to guide the development of the proposed adaptive formative assessment system. These requirements were synthesised from empirical findings and theoretical considerations and summarised in Table 2.

**Table 2.** Summary of Design Requirement

| Design Aspect                   | Description  |
|---------------------------------|--|
| Adaptive difficulty levels      | The system dynamically adjusts item difficulty based on students' responses.         |
| Formative feedback              | The system provides automated feedback to support conceptual understanding           |
| Diagnostic function             | The system maps students' learning progress and conceptual gaps                      |
| Teacher usability               | The interface is simple and aligned with the characteristics of elementary teachers. |
| Differentiated learning support | The system accommodates diverse student learning abilities                           |

The system must support adaptive item difficulty, enabling assessment items to adjust dynamically based on student responses. It should provide automated formative feedback that supports students' conceptual understanding rather than merely reporting scores. In addition, the system must function diagnostically to help teachers identify students' learning progress and conceptual gaps. From a usability perspective, the system should be designed with a simple and intuitive interface that accommodates elementary school teachers with varying levels of technological proficiency. Finally, the system should explicitly support differentiated learning by accommodating diverse student abilities and learning trajectories.

### **Results of the Design Stage: Conceptual Design of the Adaptive Formative Assessment System**

The result of the design stage is a conceptual design comprising an assessment blueprint, system adaptivity logic, an initial application prototype, and a conceptual system flow diagram, all developed prior to expert validation. This design serves as a conceptual reference for the development of the AI-based adaptive formative assessment system.

#### **Assessment Blueprint Design (Item Grid Principles)**

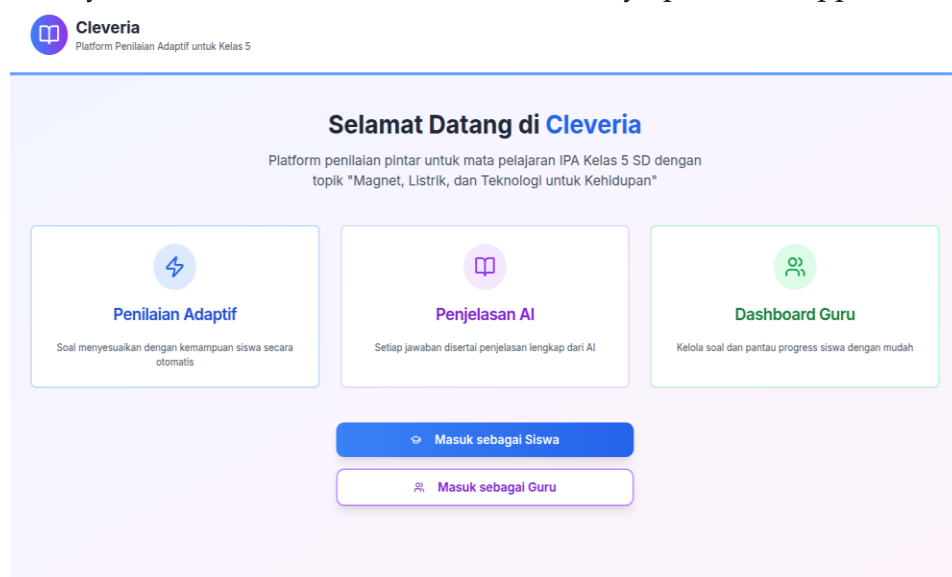
The assessment blueprint was designed to map elementary science learning objectives to formative assessment items at multiple levels of difficulty: low, medium, and high. Each learning indicator was linked to diagnostic assessment items, enabling student

responses to inform adjustments to subsequent item difficulty levels. This design ensures that formative assessment functions not only as an evaluative tool but also as a mechanism for continuously mapping students' conceptual understanding.

### Initial Application Prototype Design

The initial application design was represented through an early-stage prototype to visualize the main functional components of the proposed AI-based adaptive formative assessment system. The prototype illustrates key system features, including access to adaptive formative assessment, AI-supported explanations to assist student understanding, and a teacher dashboard for monitoring assessment progress.

The prototype was developed during the design stage and has not yet undergone expert validation or classroom implementation. Therefore, it serves as a conceptual interface representation, intended to demonstrate the alignment between identified teacher needs and the proposed system functionalities, rather than as a fully operational application.

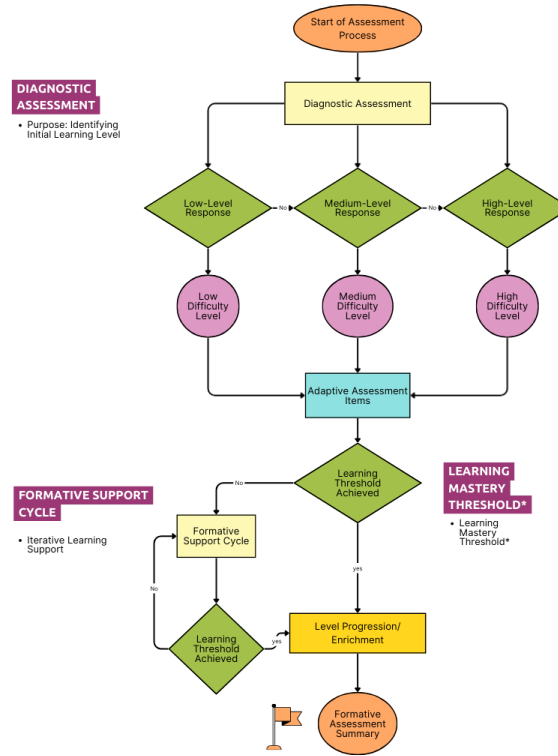


**Figure 2.** Initial Prototype of the AI-Based Adaptive Formative Assessment Application (Pre-Validation Stage)

### Conceptual System Flow Diagram

The system flow diagram illustrates the conceptual decision logic of the AI-based adaptive formative assessment system. The process begins with an initial diagnostic assessment to determine students' initial learning levels, followed by classifying student responses into low, medium, and high categories. Based on this classification, the system assigns corresponding difficulty levels and delivers adaptive assessment items. Student responses then guide subsequent assessment pathways through predefined conceptual rules, enabling iterative formative support cycles. The process continues until the learning mastery threshold is achieved, after which a formative assessment summary is generated.

This diagram demonstrates how system adaptivity is driven by student responses and how formative support is provided iteratively to support learning progression.



**Figure 3.** Conceptual Flow of an AI-Based Adaptive Formative Assessment System (Pre-Implementation Stage)

This system flow diagram represents a conceptual design output developed from the needs analysis results and is intended to guide subsequent system development stages. The diagram does not represent technical implementation, algorithmic optimization, or classroom testing, but serves as a conceptual reference for future development and empirical validation.

## D. Discussion

The results of this study address the main objective of designing a conceptual framework for an AI-based adaptive formative assessment system for elementary science learning. The conceptual model demonstrates that integrating Artificial Intelligence into formative assessment can enhance evaluation quality by providing adaptive, diagnostic, and personalized feedback. This finding reinforces the notion that assessment should not only measure learning outcomes but also facilitate learning through continuous interaction and feedback, as emphasized by Black & Wiliam (2014).

This study was conducted to address the gap between the theoretical importance of formative assessment and its practical implementation in elementary science classrooms. The discussion interprets the findings of the Analysis and Design stages by explicitly linking

them to formative assessment theory, differentiated learning principles, and prior empirical studies to answer the research questions and clarify the conceptual contribution of the proposed design.

The first research question examined what assessment-related problems and needs are experienced by elementary science teachers. The results clearly indicate that formative assessment practices remain largely homogeneous and non-adaptive, as reflected in both qualitative interview data and quantitative needs questionnaire scores. The consistently high Likert scores (4.00 on a 1–4 scale) across indicators such as adaptive difficulty, formative feedback, and usability provide concrete evidence that teachers require structured support to implement formative assessment aligned with differentiated learning principles. These findings directly support formative assessment theory, which emphasizes diagnosis of learning progress and instructional adjustment (Sadler, 2022; Heritage, 2021).

The second research question focused on how an AI-based adaptive formative assessment system can be conceptually designed to address these needs. The resulting design framework integrates an assessment blueprint, adaptive logic, formative feedback mechanisms, and teacher usability considerations. This design explicitly responds to the identified needs by translating abstract assessment principles into a coherent conceptual framework, thereby addressing a long-standing challenge in implementing formative assessment at the elementary level.

The dominance of homogeneous assessment practices identified in this study can be explained by the contextual constraints elementary teachers commonly face, including limited instructional time, administrative workload, and a lack of accessible adaptive assessment tools. These factors help explain why formative assessment is often reduced to routine testing, despite teachers' awareness of its pedagogical importance. The findings align with Hattie (2023), who argues that formative assessment fails not because of weak theory, but because of challenges in practical enactment.

In the Indonesian context of elementary education, these challenges are further shaped by curricular demands and classroom heterogeneity. Teachers are expected to address diverse learning needs within large classes, yet assessment tools rarely support adaptive decision-making. Consequently, the high demand for adaptive and easy-to-use assessment systems identified in this study reflects not only pedagogical needs but also broader systemic and contextual factors.

When compared with prior research, this study both supports and extends existing findings on AI-based assessment. Chen et al (2020) demonstrated that AI-driven adaptive assessments can improve diagnostic accuracy and learning Engagement; however, their study focused primarily on system effectiveness and algorithmic performance in secondary education contexts. In contrast, the present study does not test effectiveness. However, it extends Chen et al.'s work conceptually by embedding adaptive assessment logic within a formative assessment framework tailored specifically to elementary science learning. Similarly, Rasmini et al (2023) reported positive outcomes of technology-assisted formative assessment in Indonesian classrooms, emphasizing feasibility and learning outcomes. While

Rasmini et al (2023) focused on implementation results, the current study precedes implementation by providing a pedagogically grounded design framework that can inform and strengthen such empirical studies.

Other studies, such as Holmes et al (2019) and Hopfenbeck et al (2023), highlight the potential of AI in education but often prioritize technological innovation over pedagogical integration. The design proposed in this study addresses this limitation by explicitly aligning AI functionality with formative assessment theory and differentiated learning principles. Previous studies on digital and web-based assessment systems also indicate that technology-supported assessment can facilitate diagnostic mapping, formative feedback, and support teachers' instructional decision-making when grounded in sound pedagogical design (Subali et al., 2023; Permatasari et al., 2019; Prasetyo & Kusuma, 2020).

The key contribution of this study lies in its conceptual novelty, rather than technological advancement. While previous studies have demonstrated that adaptive assessment systems can be effective, few have articulated how such systems should be pedagogically designed to support formative assessment in elementary science learning. This study advances the field by proposing a systematic design that integrates empirical needs analysis, formative assessment theory, and adaptive logic into a unified framework. This emphasis on structured analysis and design prior to implementation aligns with design-based research in educational technology development, which underscores the importance of assessing pedagogical feasibility before system deployment (Meidya et al., 2024).

By doing so, the study moves beyond normative claims about the benefits of AI in education and provides a concrete design reference that can guide future development and empirical validation. The findings suggest that AI-based assessment systems should not be evaluated solely based on technical performance, but also on their alignment with teachers' practices, learners' developmental needs, and the broader educational context.

## E. Implication

From a theoretical perspective, this study has important implications for the development of formative assessment research by demonstrating that core formative assessment principles, such as diagnostic function, adaptivity, and meaningful feedback, can be systematically articulated within a conceptual design grounded in Artificial Intelligence (AI). These findings extend the concept of assessment for learning (Carless, 2020) by positioning adaptivity as a key element in formative assessment design, particularly in elementary science learning, where student characteristics and learning needs are highly heterogeneous. This implication also points to directions for future research to empirically test and further refine the proposed conceptual design through implementation and evaluation studies.

From a practical and policy perspective, this study highlights the need for institutional support to enhance elementary teachers' assessment literacy. The proposed system design suggests that limitations in implementing adaptive formative assessment are

not solely related to teachers' pedagogical knowledge, but also to constraints such as time availability and the lack of accessible assessment tools. Therefore, schools and education policymakers should consider integrating AI-based adaptive formative assessment systems into school-level policies, teacher training programs, and ongoing professional development initiatives. With appropriate policy support, such systems have the potential to strengthen teachers' capacity to design, implement, and utilize formative assessment more effectively, thereby supporting differentiated elementary science learning.

## F. Limitation and Suggestion for Further Research

This study has several limitations that should be acknowledged. The research was limited to the Analysis and Design stages of the ADDIE model, and therefore did not include system development, expert validation, or classroom implementation. As a result, the outcomes are confined to a conceptual design and an initial prototype, and no conclusions can be drawn about instructional effectiveness or its impact on students' learning outcomes. In addition, the proposed Artificial Intelligence (AI) component remains conceptual and rule-based, without implementing a fully data-driven machine learning model, which limits the optimization of the adaptivity mechanism. Future implementations may also face potential algorithmic bias if diverse student characteristics and socio-cultural contexts are not adequately considered (Holmes et al., 2022). Therefore, future research is strongly recommended to extend this study to the Development, Implementation, and Evaluation stages, including expert validation, limited classroom trials, and effectiveness testing using quasi-experimental research designs. Further studies should also explore integrating machine learning-based adaptivity and learning analytics to enhance system robustness and fairness, and to support teachers' instructional decision-making and assessment literacy in elementary science education (Zhai et al., 2021).

## G. Conclusion

This study achieved its objective by developing a pedagogically grounded conceptual framework for an AI-based adaptive formative assessment system to support differentiated elementary science learning. The proposed framework integrates formative assessment principles, adaptive assessment logic, and teachers' practical needs into a coherent design that emphasizes diagnostic and learning-oriented assessment. The main scientific contribution of this study lies in its conceptual advancement, providing a structured design framework that positions AI as an integral component of formative assessment practice in elementary science education. This contribution strengthens the theoretical foundation for future system development and empirical research on adaptive formative assessment in primary education.

## References

- Balitbang Kemendikbud. (2020). *Laporan Hasil Ujian Nasional Sekolah Dasar Tahun 2020*. Kementerian Pendidikan dan Kebudayaan Republik Indonesia.













- Black, P., & Wiliam, D. (2014). *Inside the Black Box: Raising Standards Through Classroom Assessment* (Rev. ed.). GL Assessment.
- Branch, R. M. (2009). *Instructional Design: The ADDIE Approach*. Springer. <https://doi.org/10.1007/978-0-387-09506-6>
- Carless, D. (2020). Long-Term Perspectives on Learning-Oriented Assessment. *Assessment & Evaluation in Higher Education*, 45(6), 993–1002. <https://doi.org/10.1080/02602938.2020.1726921>
- Chen, X., Xie, H., Zou, D., & Hwang, G.-J. (2020). Application and Theory Gaps During the Rise of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, 1, 100002. <https://doi.org/10.1016/j.caeai.2020.100002>
- Diana, D., & Kartika, A. (2024). Deskripsi Keterampilan Asesmen dan Stimulasi HOTS Guru Sekolah Dasar: Studi Kualitatif. *Jurnal Psikohumanika*, 16(1), 60–74.
- Earl, L. M. (2013). *Assessment as Learning: Using Classroom Assessment to Maximize Student Learning* (2nd ed.). Corwin Press.
- Hattie, J. (2023). *Visible Learning: The Sequel: A Synthesis of Over 2,100 Meta-Analyses Relating to Achievement*. Routledge. <https://doi.org/10.4324/9781003380542>
- Hattie, J., & Clarke, S. (2018). *Visible Learning: Feedback* (1st ed.). Routledge. <https://doi.org/10.4324/9780429485480>
- Heritage, M. (2021). *Formative Assessment in Practice: A Process of Inquiry and Action*. Harvard Education Press.
- Hopfenbeck, T. N., Zhang, Z., Sun, S. Z., Robertson, P., & McGrane, J. A. (2023). Challenges and Opportunities for Classroom-Based Formative Assessment and AI: A Perspective Article. *Frontiers in Education*, 8, 1270700. <https://doi.org/10.3389/educ.2023.1270700>
- Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial Intelligence in Education: Promises and Implications for Teaching and Learning*. Center for Curriculum Redesign.
- Holmes, W., Porayska-Pomsta, K., Holstein, K., Sutherland, E., Baker, T., Shum, S. B., Santos, O. C., Rodrigo, M. T., Cukurova, M., Bittencourt, I. I., & Koedinger, K. R. (2022). Ethics of AI in Education: Towards a Community-Wide Framework. *British Journal of Educational Technology*, 53(3), 739–755. <https://doi.org/10.1111/bjet.13171>
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence Unleashed: An Argument for AI in Education*. Pearson.
- Meidya, L., Haryani, S., Wijayati, N., Avrilianda, D., & Subali, B. (2024). Pengembangan Mobile Learning Berbasis RADEC pada Materi Sistem Pencernaan untuk Melatih Literasi Digital dan Hasil Belajar Kognitif Siswa. *Jurnal Pendidikan Biologi Undiksha*, 11(3), 70–83.

- OECD. (2019). *PISA 2018 Results (Volume I): What Students Know and Can Do*. OECD Publishing. <https://doi.org/10.1787/5f07c754-en>
- Permatasari, G. A., Ellianawati, E., & Hardyanto, W. (2019). Online Web-Based Learning and Assessment Tool in Vocational High School for Physics. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 5(1), 1–8. <https://doi.org/10.21009/1.05101>
- Prasetyo, Z. K., & Kusuma, A. B. (2020). Pengembangan Four-Tier Online Diagnostic Test Berbasis Web untuk Mendiagnosis Pemahaman Konsep Siswa. *Jurnal Penelitian dan Pengembangan Pendidikan*, 14(1), 45–58.
- Rasmini, N. W., Antara, P. A., & Wulandari, I. G. A. A. M. (2023). The Use of Technology-Based Formative Assessment in Improving Mathematics Achievement of Elementary School Students. *Journal of Education Technology*, 7(3), 497–503. <https://doi.org/10.23887/jet.v7i3.67770>
- Sadler, D. R. (2022). Three In-Course Assessment Reforms to Improve Higher Education Learning Outcomes. *Assessment & Evaluation in Higher Education*, 47(2), 167–183. <https://doi.org/10.1080/02602938.2021.1903063>
- Subali, B., Ellianawati, Faizah, Z., & Sidiq, M. (2023). Indonesian National Assessment Support: Can RE-STEM Android App Improve Students' Scientific Literacy Skills? *International Journal of Evaluation and Research in Education*, 12(3), 1399–1407. <https://doi.org/10.11591/ijere.v12i3.24794>
- Wylie, E. C., & Lyon, C. J. (2021). Formative Assessment for Learning: Science, Theory, and Practice. *Review of Education*, 9(2), e3283. <https://doi.org/10.1002/rev3.3283>
- Zakiyyah, H., Sutopo, Y., Harianingsih, T., Subali, B., & Widiari, N. (2025). Literature Review: Differentiated E-Worksheets to Boost Primary School Learning Outcomes Between 2020–2025. *Edunesia: Jurnal Ilmiah Pendidikan*, 6(2), 808–821. <https://doi.org/10.51276/edu.v6i2.1216>
- Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., Liu, J.-B., Yuan, J., & Li, Y. (2021). A Review of Artificial Intelligence (AI) in Education From 2010 to 2020. *Complexity*, 2021, Article 8812542. <https://doi.org/10.1155/2021/8812542>

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