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The Analysis Needs Mapping for the Development of an Artificial Intelligence-Item Response Theory (AI-IRT)-Based CAT Web System for Adaptive Science Assessment

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ABSTRACT

Assessment of science learning outcomes in junior high school science education is still largely dominated by conventional tests that do not adequately accommodate differences in students' abilities and provide limited diagnostic feedback. This limitation highlights the need for a more adaptive and data-driven assessment system. This study aims to map the needs for developing a web-based Computerized Adaptive Test (CAT) system integrating Artificial Intelligence and Item Response Theory (AI-IRT) for science assessment at the junior high school level. The study employed a descriptive qualitative approach at the Analysis stage of the ADDIE development model. Data were collected through semi-structured interviews with one junior high school science teacher and five students, and analyzed using NVivo through open coding, axial coding, and selective coding. The findings reveal six key needs: adaptive assessment systems, measurement fairness and precision, diagnostic feedback, efficiency and automation, infrastructure readiness, and user-friendly interface design. These findings demonstrate the potential of integrating AI and IRT to support more accurate, personalized, and efficient science assessment. The results provide a conceptual and operational foundation for developing an AI-IRT-based CAT web system tailored to junior high school science learning.

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1. INTRODUCTION

Assessment of learning outcomes is a fundamental component of the education system because it serves as the basis for academic decision-making, mapping student abilities, and improving the learning process [1]. At the Junior High School level, especially in the Natural Sciences subject, assessment not only requires mastery of concepts, but also

logistical, analytical, and applicative thinking skills that require the support of a technology-based learning system that is relevant to current developments [2]. However, assessment practices, which are still dominated by paper-based written tests, tend to apply the same questions to all students without considering differences in individual abilities. At the same time, the transformation of education in the era of artificial intelligence demands a more adaptive and contextual approach [3], [4]. This condition has the potential to create a mismatch between the level of question difficulty and student ability, where some students find questions too easy while others find them too difficult, thus indicating the need for AI-based innovation in the education system [5]. Consequently, test results often do not fully represent students' actual abilities accurately and fairly. In addition, the manual correction process takes a relatively long time and makes it difficult for teachers to provide quick and in-depth feedback.

The development of information technology and artificial intelligence opens up opportunities to transform conventional assessment systems to be more adaptive, efficient, and personalized at various levels of education [6], [7]. The Computerized Adaptive Test (CAT), developed based on the Item Response Theory (IRT) approach, allows the system to dynamically adjust the difficulty level of questions based on student responses, in line with the increasing use of AI literacy in Indonesian education [8], [9]. Through this mechanism, each student can gain a testing experience tailored to their ability level, resulting in a more precise measurement process with a more efficient number of questions, as has been the case with various AI-based learning media innovations developed in elementary [10], [11]. The integration of AI into web-based systems also enables automatic data analysis, the provision of diagnostic feedback, and individualized mapping of material mastery within the dynamics of AI-based learning [12], [13], [14]. In junior high school science learning, which is characterized by conceptual and computational material, an AI-IRT-based adaptive system has the potential to support fairer, more objective assessments and personalized learning. Therefore, the development of a web-based adaptive assessment system integrating Artificial Intelligence and Item Response Theory becomes a strategic effort to improve the quality, efficiency, and accuracy of science assessment at the junior high school level.

Several studies have examined the use of artificial intelligence in the context of education and the transformation of technology-based learning systems. Afrita found that the application of artificial intelligence can improve the efficiency and effectiveness of the education system, particularly in data management, learning evaluation, and optimizing academic processes [15]. Asbara et al. demonstrated that the use of AI as a learning aid at the elementary school level can increase student engagement, facilitate teacher delivery, and support a more interactive learning process [16]. Cahyaningrum explained that the application of artificial intelligence using a fuzzy logic approach in education can facilitate more accurate and adaptive decision-making processes based on student data [17]. Kurniawati et al. concluded that AI plays a significant role in supporting technology-based learning in the era of educational digitalization through system automation, learning personalization, and improving the quality of evaluation [18].

Although these studies have discussed the role of artificial intelligence in improving the efficiency, interactivity, and quality of technology-based learning, most of them focus

on the general implementation of AI in learning environments or the development of AI-based learning media. Research that specifically investigates the development of adaptive assessment systems combining Artificial Intelligence, Item Response Theory, and Computerized Adaptive Testing remains limited, particularly in the context of junior high school science education in Indonesia. In addition, previous studies rarely place user needs analysis involving both teachers and students as a systematic foundation in the early stage of system development. Therefore, this study focuses on conducting a needs mapping analysis as the initial stage in the development of an AI-IRT-based Web Computerized Adaptive Test system. This needs analysis is conducted using the Analysis stage of the ADDIE development model in order to identify the expectations, challenges, and system requirements from the perspective of users.

Therefore, this study aims to map the needs for developing an AI-IRT-based Web CAT system for junior high school science lessons through in-depth interviews with teachers and students at the ADDIE Analysis model stage. The results of this study are expected to provide both theoretical and practical contributions, including strengthening the theoretical foundation of needs assessment in the development of adaptive assessment systems and providing practical guidance for designing web-based CAT systems that are more relevant, fair, efficient, and aligned with user needs in junior high school science learning.

2. METHOD

This research uses a descriptive qualitative approach focused on needs analysis at the Analysis stage of the ADDIE development model. This approach aims to gain an in-depth understanding of user needs for the development of a web-based adaptive assessment system in the context of junior high school science learning.

The research subjects consisted of one junior high school science teacher and five eighth-grade students from two different schools, selected purposively based on the following criteria: (1) active involvement in science assessment practices, and (2) readiness to use technology in the learning and evaluation process.

The research instrument was a semi-structured interview guide developed based on a literature review on Computerized Adaptive Testing, Item Response Theory, the integration of Artificial Intelligence in learning evaluation, and the principles of needs analysis in the ADDIE model. The interviews were designed to uncover: (1) current science assessment practices, (2) perceptions of question difficulty and fairness, (3) experience and readiness to use technology in web-based tests, (4) expectations for the AI-based Web CAT system, (5) needs for diagnostic feedback and personalized learning, and (6) aspects of the system's practicality and usability.

Instrument Validity

The instrument's content validity was assessed through expert judgment involving two experts: one learning evaluation expert and one educational technology expert. The assessment focused on the suitability of the questions to the system's needs indicators, the representation of the AI-IRT-based Web CAT constructs, clarity of wording, and relevance

to the research objectives. Input from the experts was used to revise and refine the instrument before use in data collection.

In addition to content validity, a limited face validity test was conducted with one student outside the research subjects to ensure that each question was comprehensible and aligned with the cognitive characteristics of junior high school students. Feedback from this test was used to simplify technical terms and clarify the question structure to avoid multiple interpretations. Thus, the instrument was deemed suitable for use in the data collection process.

Data Collection and Analysis

Data collection was conducted through the following stages: (1) instrument development and validation, (2) conducting interviews with data recording after obtaining respondent consent, (3) verbatim transcription of interview results, and (4) data analysis using NVivo software. The interviews were conducted individually with each participant and lasted approximately 30–45 minutes. This duration allowed participants to explain their experiences and perspectives regarding science assessment practices and expectations for an adaptive assessment system in greater depth.

During the interview process, all conversations were audio-recorded with the participants' consent to ensure the completeness and accuracy of the data collected. The recordings were then transcribed verbatim into written form. The transcription process involved converting the entire interview recordings into textual data while maintaining the original meaning of the participants' responses. The transcripts were carefully reviewed and verified before being imported into NVivo software for further analysis. The analysis was conducted through open coding, axial coding, and selective coding to identify key categories and themes of system requirements.

Data collection was conducted until data saturation was reached. Data saturation was determined when the interview data no longer produced new information or themes relevant to the research objectives, and the responses from participants began to show recurring patterns. In this study, saturation was observed after the sixth participant, where additional interviews did not generate new categories related to the needs for developing the AI-IRT-based Web CAT system.

Data validity was maintained through source triangulation between teachers and students to compare the consistency of the information obtained. Furthermore, member checking was conducted by reconfirming the interview summary with respondents to ensure the accuracy of interpretation and enhance the credibility of the research findings.

The results of the analysis phase were used as the basis for formulating the functional and non-functional requirements specifications for the AI-IRT-based Web CAT system, which will be developed in the next phase of the ADDIE model.

3. RESULTS AND DISCUSSION

3.1. Results

The results of the analysis of teacher and student interview data using NVivo software during the ADDIE Analysis model stage resulted in a mapping of the needs for

developing an AI-IRT-based Web CAT system, visualized through a word cloud in Figure 1.

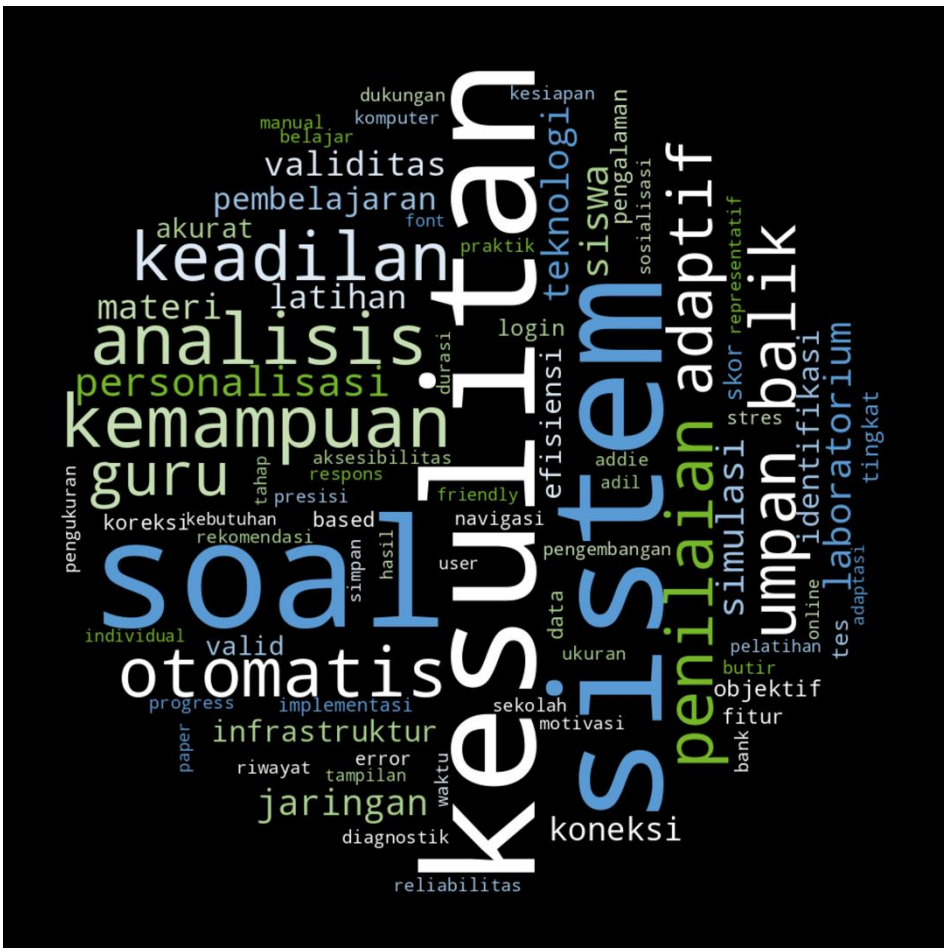

Figure 1. Word Cloud Resulting from NVivo Analysis

Based on the NVivo word cloud visualization in Figure 1, the most dominant words appearing are system (Sistem), difficulty (Kesulitan), question (Soal), assessment (Penilaian), ability (Kemampuan), adaptive (Adaptif), feedback (Umpan Balik), and analysis (Analisis). The dominance of the word "system (Sistem)" indicates that the primary concern of respondents, both teachers and students, is focused on the need to develop a more structured, integrated, and technology-based assessment system. This indicates an awareness of the limitations of the conventional evaluation system still used in science learning.

The simultaneous appearance of the words "difficulty (Kesulitan)", "question (Soal)" and “ability (Kemampuan)" indicates a fundamental problem: the mismatch between the difficulty level of questions and individual student abilities, a central issue in current science assessment practices. Furthermore, the emergence of the words "adaptive (Adaptif)" and "analysis (Analisis)" reflects respondents' expectations for a system that not only adjusts to the difficulty level of questions but also provides a more accurate and comprehensive analysis of the results. Meanwhile, the emergence of the word "feedback (Umpan Balik)" confirms that students require evaluations that go beyond numerical scores. They expect discussion of questions, error identification, and material recommendations as part of the system's diagnostic function. Overall, the results of the wordcloud visualization indicate that

the need for system development centers on three main aspects: personalized assessment, fairness and precision of measurement, and adequate technological support. These three aspects form the conceptual foundation for the Analysis stage of the ADDIE model, which will then guide the design of an AI-IRT-based Web CAT system to address the pedagogical and operational needs of a junior high school science learning environment.

Table 1. Summary of the Main Themes of NVivo Analysis Based on Word Frequency and Field Coding

Yes	Main Themes	Dominant Keywords	Data Source	Development Implications
1	Need for an Adaptive System	System, Adaptive, Difficulty, Ability	Teachers & Students	Development of an AI-IRT-based CAT that adjusts the difficulty level of the questions
2	Measurement Fairness and Precision	Fair, Accurate, Validity, Analysis	Teachers & Students	IRT integration to improve assessment precision and objectivity
3	Diagnostic Feedback	Feedback, Recommendations, Results Report	Students	Provision of automatic question discussions and material recommendations
4	Efficiency and Automation	Automatic, Correction, Efficiency, Question Bank	Teacher	Automated item analysis and data-driven question bank management
5	Infrastructure and Technical Readiness	Lab, Network, Login, Error	Teachers & Students	Robust system with auto-save features and technical support
6	Interface Design and Convenience	Display, Navigation, Duration, User Friendly	Students	Simple, responsive, and easy-to-use UI/UX design

Table 1 shows that the NVivo coding results grouped the data into six interrelated main themes. The first theme, "Need for an Adaptive System," and the second, "Fairness and Precision of Measurement," emphasized that respondents' core need lies in developing an assessment system capable of adapting the difficulty level of questions to individual students' abilities fairly and accurately. These two themes reflect the urgency of implementing an Item Response Theory (IRT)-based approach within a Computerized Adaptive Testing (CAT) framework to improve the validity and objectivity of measurement results. The third theme, "Diagnostic Feedback," and the fourth, "Efficiency and Automation," relate to the pedagogical and professional functions of the system. From a pedagogical perspective, students expect a system capable of providing informative results reports, including discussion of questions and automated material recommendations. In terms of professionalism, teachers emphasized the importance of efficiency in the process of correcting and analyzing test item quality through automation mechanisms and data-based question bank management. Meanwhile, the fifth and sixth themes highlighted technical aspects and user experience, which are crucial factors in implementing web-based systems.

The combination of dominant word frequency and field categorization results demonstrates that development needs are not only technological, but also pedagogical and operational.

Table 2. Synthesis of Needs Analysis Results at the ADDIE Model Analysis Stage

Analysis Aspect	Key Findings	Problem Indications	System Requirements
Problem Analysis	Uniform questions are not according to individual abilities	Injustice and incongruity of difficulty level	AI-IRT-based adaptive system
User Analytics	Students need detailed and personalized feedback	The numerical value is not informative enough	Automated material diagnostics and recommendations features
Task Analysis	Teachers have difficulty correcting and analyzing the quality of questions	The manual process is time-consuming	Automated item analysis and integrated question bank
Context Analysis	Dependency on networks and devices	Risk of errors and technical glitches	Robust web system and automatic storage
Readiness Analysis	Students and teachers are ready but need training	Unusual use of adaptive systems	System training, simulation, and socialization modes

Table 2 presents a comprehensive synthesis of the needs analysis results based on the five main aspects of the Analysis stage of the ADDIE model: problem analysis, user analysis, task analysis, context analysis, and readiness analysis. This synthesis integrates field findings with system implications for development. From a problem analysis perspective, the use of uniform questions was identified as incapable of accommodating differences in individual student abilities. This situation led to measurement inequities and inconsistent question difficulty levels, thus underscoring the urgency of developing an adaptive AI-IRT-based system capable of dynamically adjusting difficulty levels based on estimated student abilities.

In terms of user analysis, students expressed a need for more detailed, personalized, and informative feedback. Numerical scores alone were deemed insufficient to provide a comprehensive picture of learning outcomes. Therefore, the developed system needs to be equipped with an automatic diagnostic feature capable of presenting question discussions, identifying weaknesses, and recommending materials in a structured manner.

The task analysis revealed that teachers face challenges in the manual correction process and item quality analysis, which require significant time and effort. This indicates the need for a system that supports automated item analysis and integrated, data-driven question bank management to improve the efficiency and accuracy of the evaluation process.

Furthermore, the context analysis revealed that system implementation is highly dependent on network availability and supporting devices. This dependency poses potential risks such as system errors and other technical disruptions. Therefore, the developed system must have a high level of robustness, including auto-save features and data recovery mechanisms.

In the readiness analysis aspect, both teachers and students demonstrated readiness to adopt a technology-based system, although training and socialization are still needed to reduce unfamiliarity with the adaptive testing mechanism. Therefore, the system needs to provide practice modes, simulations, and user guides as part of the implementation strategy.

Overall, the findings from the Analysis phase indicate that the main problem lies not only in the mismatch between the difficulty level of the questions and the students' abilities but also in the limitations of conventional assessment systems in providing fast, accurate, and comprehensive feedback. Teachers require efficiency and precision in the evaluation process, while students expect a fairer, more adaptive, and more informative assessment experience.

This synthesis confirms that the development of an AI-IRT-based Web CAT system must be designed multidimensionally. In addition to integrating an adaptive IRT-based algorithm to improve measurement accuracy, the system also needs to consider pedagogical functionality, infrastructure readiness, ease of use, and implementation support. Therefore, development at the Design and Development stage within the ADDIE framework must accommodate usability, robustness, and instructional support as integral parts of the system design.

3.2. Discussion

Research findings from the ADDIE Analysis model indicate that the primary need for teachers and students lies in the development of an assessment system that is adaptive, precise, and capable of providing automated diagnostic feedback. The dominant themes of system, difficulty, ability, and adaptability in the NVivo analysis indicate a gap between conventional assessment practices and the needs of data-driven learning. These results align with Owan et al., who stated that the use of Artificial Intelligence (AI) in education serves to improve the accuracy of data processing and the efficiency of the learning evaluation process [19], [20]. Furthermore, Yahya and Hidayat emphasized that the implementation of AI in the era of the Fourth Industrial Revolution (IPR) enables the education system to move toward a more responsive, intelligent technology-based model [21]. In the context of this research, the integration of the AI-IRT-based Web CAT (CAT) is a concrete manifestation of this transformation, particularly in the junior high science learning evaluation system.

Furthermore, the need for personalized learning and adjustment of question difficulty based on individual student abilities was a central finding. Students expect a system that does not provide uniform questions but instead adapts to previous responses, thus creating a more equitable and proportionally challenging testing experience. This finding is consistent with Wardhani, who explained that AI systems for personalized learning can optimize learning paths based on student profiles [22]. Yanto et al. also emphasized that AI-based educational personalization contributes to improving learning quality through specific material recommendations based on student performance data [23]. Thus, the use of the IRT approach in CAT is not only technically relevant in improving measurement precision but also pedagogically relevant in supporting differentiated learning.

In terms of system efficiency and digitalization, teachers expressed the need for automated item analysis, data-driven question bank management, and a reduction in the

burden of manual corrections. These findings reinforce the urgency of digitizing educational information systems, as stated by Nugroho et al., who stated that developing a digital-based educational information system can improve the effectiveness of learning evaluation governance [24]. Khoiriah et al. also explained that the development of educational management systems in the Society 5.0 era demands the integration of intelligent technology into academic processes, including evaluation and monitoring of learning outcomes [25]. In this context, the AI-IRT-based Web CAT is not only an evaluation tool but also part of an integrated, analytics-based educational information system ecosystem.

In addition to technical and pedagogical aspects, the research results also indicate that infrastructure readiness and implementation support are crucial factors in system development. Respondents highlighted potential network constraints, system errors, and the need for training for teachers and students. This aligns with Alzghaibi, who stated that developing an artificial intelligence-based learning system requires technical readiness and robust system design for optimal performance, particularly in the context of distance learning [26]. Syawaludin also emphasized that the use of AI in learning strategies in elementary education must consider user readiness and technical support to prevent resistance to innovation [27]. Therefore, the Analysis stage of this study not only identifies the functional requirements of the system but also the contextual and implementative needs that must be considered in the Design and Development stages.

This study provides an original contribution by systematically mapping user needs as the foundational stage for developing an AI-IRT-based Web CAT system specifically for junior high school science assessment. While previous studies have primarily focused on the implementation of artificial intelligence in learning media or general educational technologies, this study emphasizes the importance of needs analysis involving both teachers and students as key stakeholders in adaptive assessment system design. From the perspective of instructional design theory, particularly within the ADDIE framework, the findings strengthen the role of the Analysis stage as a critical step in identifying functional, pedagogical, and technological requirements prior to system development. This study demonstrates that integrating user needs analysis with adaptive assessment concepts can guide the development of more contextually relevant and user-oriented digital evaluation systems.

Furthermore, this research contributes to the growing body of adaptive assessment research by highlighting how the integration of Artificial Intelligence and Item Response Theory can support the development of adaptive testing environments that are not only technically precise but also pedagogically meaningful. The needs identified in this study, such as adaptive difficulty adjustment, automated diagnostic feedback, and data-driven question bank management, provide practical design considerations for future CAT systems in secondary education contexts. Thus, the findings extend current discussions in adaptive assessment by emphasizing the role of user-centered needs analysis in bridging the gap between measurement theory and practical instructional implementation.

Although this study successfully mapped the development needs of an AI-IRT-based Web CAT system comprehensively through NVivo analysis, several limitations warrant consideration. First, the limited number of participants (one teacher and five students) means

that generalizations of the findings remain contextual. Second, the data used were derived from interviews, thus relying heavily on the subjective perceptions of respondents, despite source triangulation. Third, this study focused only on the Analysis stage of the ADDIE model, thus failing to test the system's effectiveness at the implementation and evaluation stages. Therefore, further research is needed to involve a wider range of participants, develop a system prototype, and conduct empirical trials to measure the actual impact of using AI-IRT-based Web CAT on junior high school science learning outcomes.

4. CONCLUSION

This study concludes that the Analysis phase of the ADDIE model plays a crucial role in identifying fundamental requirements for developing an adaptive assessment system that integrates Artificial Intelligence and Item Response Theory in junior high school science education. The needs mapping results indicate that both teachers and students desire an assessment system that is adaptive, precise, efficient, and capable of providing diagnostic feedback to support more personalized learning evaluations.

These findings highlight the importance of incorporating user needs analysis as a fundamental step in designing a technology-based adaptive assessment system. From a theoretical perspective, this study contributes to the development of instructional design and adaptive assessment research by demonstrating how needs analysis can guide the formulation of functional and pedagogical requirements for an AI-IRT-based Computerized Adaptive Testing system. From a practical perspective, these results provide initial guidance for developers and educators in designing an adaptive web-based assessment system that aligns with user expectations and the educational context.

The limitations of this study lie in the limited number of participants and the focus on the Analysis phase, which has not yet empirically tested the system's effectiveness. Therefore, the findings should be interpreted in the context of an exploratory needs analysis and may not yet represent the implementation of a large-scale adaptive assessment system.

Future research is recommended to advance to the next stage of the ADDIE model by developing a functional prototype of an AI-IRT-based Web CAT system, conducting large-scale system testing in various school settings, and evaluating its impact on student learning outcomes, learning motivation, and assessment fairness. In the broader educational field, this research contributes to the ongoing transformation of digital assessment practices by providing an initial framework for developing data-driven adaptive assessment systems that can support more equitable and personalized learning in secondary education.

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