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The Validation of Artificial Intelligence Integrated E-Module with Problem Based Learning Model on Renewable Energy to High School Students' Critical Thinking Skills

Habil Ihsan[1*], Festiyed[1], Emiliannur[1], Selma Riyasni[1]

[1] *Department of Physics, Universitas Negeri Padang, Jl. Prof. Dr. Hamka Air Tawar Padang 25131, Indonesia*
Corresponding author. Email:h48ilihsan@student.unp.ac.id

ABSTRACT

The 21st century demands strong critical thinking, a skill often lacking in Indonesian 10th-grade physics students despite curriculum reforms. Current teaching materials often fail to adequately engage students or foster higher-order thinking skills. To bridge this gap, this research aimed to develop and validate an innovative Artificial Intelligence (AI)-integrated e-module on renewable energy, utilizing a Problem-Based Learning (PBL) model. Using the Analysis, Design, and Development (ADDIE) model, the study focused on the initial three stages, culminating in expert validation. The e-module was developed using WordPress and validated by three physics experts from Universitas Negeri Padang using a rigorous instrument adapting six indicators: material substance, visual communication, software utilization, learning design, PBL model, and AI integration. The results demonstrated high feasibility, with the e-module achieving a "very valid" category across all indicators (average score > 0.83). These findings confirm that the AI-integrated e-module is a scientifically accurate, engaging, and pedagogically sound tool suitable for enhancing students' critical thinking skills in physics education.

Keywords: E-Module; Artificial Intelligence; Problem Based Learning; Critical Thinking Skills; Renewable Energy

I. INTRODUCTION

The rapid advancements in technology and information in the 21st century necessitate a fundamental transformation in educational paradigms. Education now focuses on developing four key competencies: critical thinking, creative thinking, collaboration, and communication [1]. Among these, critical thinking serves as an essential foundation for shaping adaptive individuals capable of navigating global dynamics [2]. This skill empowers students to grasp abstract concepts, think logically, and formulate alternative solutions [3] . In response to this need, the Indonesian Government introduced the Merdeka Curriculum to improve educational quality by emphasizing material comprehension and critical thinking [4, 5]. However, field observations and literature reviews reveal that the implementation of this curriculum has not yet fully succeeded in boosting the critical thinking abilities of 10th-grade high school students, particularly in Physics. Observations at Padang Public Senior High School 4 indicated low performance across Facione's critical thinking indicators, with scores for interpretation, analysis, and inference falling below 50%.

A primary contributing factor is the lack of interactive and stimulating teaching materials. Interviews with physics teachers revealed that existing textbooks and handouts are often monotonous and fail to support student motivation. Furthermore, while students have access to technology like smartphones, it is rarely utilized effectively for educational purposes in the classroom. Students expressed a need for ICT-based, interactive learning media that addresses real-world issues, such as environmental challenges [6]. To address this gap, E-modules emerge as a promising solution [7]. E-modules can be designed with adaptable content, multimedia, and interactive features to improve motivation and learning outcomes. To further enhance critical thinking, these modules must be grounded in effective pedagogical models [8]. The Problem-Based Learning (PBL) model is particularly suitable, as it presents students with authentic problems that require investigation and problem-solving [9, 10].

Moreover, the integration of Artificial Intelligence (AI) in education offers transformative potential. AI can provide real-time support, personalized learning paths, and automated feedback [11, 12]. By combining PBL

with AI, an e-module can offer a personalized and interactive learning experience that fosters deep critical thinking through complex case analysis [13, 14]. This study focuses on "Renewable Energy", a topic that requires strong visual representation and is highly relevant to students' daily lives [15]. The research aims to develop and validate an AI-integrated e-module with a PBL model on renewable energy. The goal is to provide a validated, innovative tool to bridge the gap between traditional learning and technological advancements, ultimately strengthening students' critical thinking skills.

II. METHOD

This research utilizes the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) as a guide for developing dynamic learning tools [16] . This study is limited to the first three stages: Analysis, Design, and Development. The limitation to these stages is due to the focus on ensuring the product's validity and feasibility through expert judgment before proceeding to large-scale classroom implementation and effectiveness evaluation in future research [17]. The ADDIE model is illustrated in Figure 1.

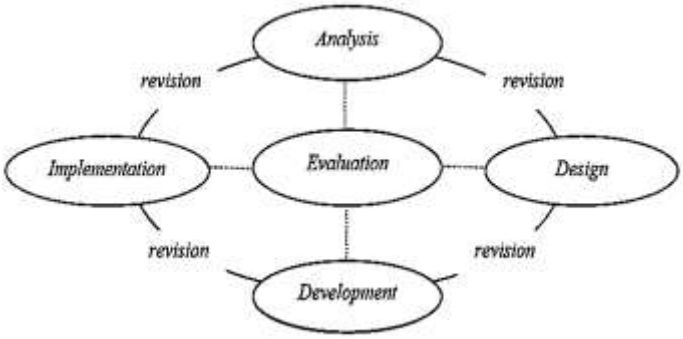

Fig. 1. Illustration of the ADDIE Model Procedures

Based on Figure 1, the following research procedures were carried out: (1) *Analysis*: In the analysis phase, this research focuses on gathering and examining information to define the problem and plan for the development of an AI-integrated e-module with problem-based learning (PBL) model. This stage involves needs analysis to identify discrepancies in current learning conditions in school (Padang Public Senior High School 4), specifically focusing on renewable energy material, and a literature study analysis to review relevant references such as books, journals, and articles, particularly concerning AI-integrated e-modules with PBL model, renewable energy, and critical thinking skills; (2) *Design*: Following analysis, the design phase involves creating a prototype. This includes designing learning material components like learning objectives and activities, then designing the product itself as an AI-integrated e-module with PBL model for 10th-grade students on renewable energy to improve critical thinking. Finally, content and media design combine various interactive elements and integrates AI according to the PBL model. (3) *Development*: The development phase then involves creating the product using WordPress to build the AI-integrated e-module as a website. This is followed by self-evaluation to identify initial errors based on feature completeness and conceptual alignment, leading to necessary improvements.

The validation subjects were three expert Physics lecturers from Universitas Negeri Padang. The validity instrument was adapted from the "Practical Guide to Develop E-modules" [18]. It assessed six indicators: The first, material substance, ensures content quality through four components: veracity, material completeness, contemporary, and readability. Second, visual communication focuses on user experience and aesthetic appeal, measured by six elements: effective navigation, clear letters, appropriate colors, logical layout, suitable media, and engaging animation. Third, software utilization assesses the resource's technical aspects with three criteria: interactivity, the use of supporting software, and originality in its implementation. Fourth, learning design scrutinizes the pedagogical structure through fifteen components, ranging from foundational elements like the cover and table of contents to core instructional parts such as learning outcomes, material, and exercises. It also includes evaluative and reflective sections like worksheets, evaluation, and reflection, culminating with a bibliography and appendices. Fifth, the Problem-Based Learning model is integrated with five distinct syntax components. Finally, Artificial Intelligence integration enhances the resource through two components: the integration of analysis and feedback, and the integration of interaction and motivation.

The expert validation questionnaire aimed to determine the feasibility of the AI-integrated e-module before testing it on students in schools. The validity test used a validation questionnaire instrument using a Likert scale. The AI-integrated e-module is considered suitable for use if it achieves a high validity percentage. The final validation results of this e-module were obtained based on a questionnaire assessed by lecturers from the Physics Department of UNP. The assessment of the validity test questionnaire was based on the following Likert scale.

Table. 1. Linkert Scale

Scale	Rating
1	Strongly Disagree
2	Disagree
3	Agree
4	Strongly Agree

(Source: Ref [19])

The data obtained will be analyzed using the Cohen's Kappa formula with the following equation.

$$\rho_0 = \frac{Realized\ Value}{Total\ Value} \quad (1)$$

$$\rho_e = \frac{Unrealized\ Value}{Total\ Value} \quad (2)$$

$$K = \frac{\rho_0 - \rho_e}{1 - \rho_e} \quad (3)$$

Information:

K = Kappa Moment Index
ρ_0 = Realized Proportion
ρ_e = Unrealized Proportion

After the kappa moment results are obtained, they are divided into three category indices. The following are the five category indices based on Cohen's Kappa Index.

Table. 2. Validity Category Interval

Interval	Rating
0,00 – 0,20	Poor Agreement
0,21 – 0,40	Slight Agreement
0,41 – 0,60	Fair Agreement
0,61 – 0,80	Moderate Agreement
0,81 – 1,00	Substantial Agreement

(Source: Ref [20])

III. RESULTS AND DISCUSSION

Result

The teaching material created is an artificial intelligence integrated e-module with problem-based learning model on renewable energy material to improve critical thinking skills of grade 10 high school students. Developed following an adaptation of the Practical Guide for Developing E-Modules, this comprehensive resource features a well-structured layout beginning with a Cover, Foreword, and a hyperlinked Table of Contents. The Introduction provides essential information including the e-module's identity, user instructions, and a clear breakdown of the PBL syntax. Learning Competencies are laid out clearly in concept maps and learning outcomes to guide students. The center of the module is its AI-Integrated Learning Activities consisting of detailed lesson materials, summaries, worksheets for students, and exercises painstakingly prepared to enhance critical thinking. Additionally, the Evaluation section includes a final test, a unique critical thinking skills rubric, and creative AI-integrated feedback answers for immediate and personalized insights. Finally, the Conclusion offers a long glossary, a bibliography of further reading, and an appendices. As shown in Figure 2, the module includes a cover, interactive contents, PBL-based activities, AI-integrated feedback mechanisms, and critical thinking evaluations.

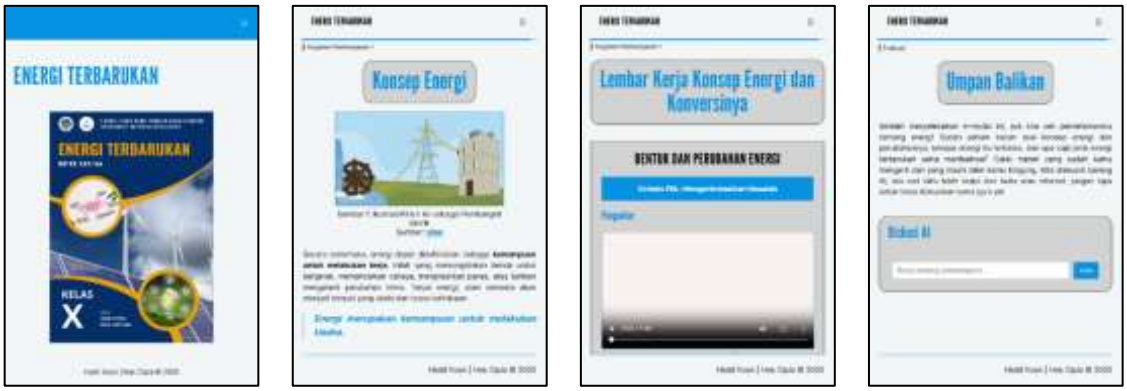

Fig. 2. AI Integrated E-module Product with PBL Model of Renewable Energy Material

After creating the product, the next step is product validation. Based on input from the validators, this e-module was then revised comprehensively, including the addition of a scoring system to the critical thinking rubric, improvements to the AI input and responses per question, adjustments to practice questions and evaluations with indicators of critical thinking skills, variations in learning activities on student worksheets with simulations and simple experiments, adjustments to the arrangement of worksheet activities according to PBL syntax, improvements to the beginning of the material with definitions, and improvements to the e-module display with more attractive navigation icons and animations to increase student interest. Following development, the e-module was validated by three experts. The detailed results for each indicator are presented below.

A. Material Substance Result

In the Material Substance indicator, there are four components, including: (1) Veracity with a value of 0.80 or valid. This shows that the truth of the material presented is in accordance with scientific principles, tested, factual, and rational; (2) Material Completeness with a value of 0.80 or valid. This shows that the material presented is complete, exploratory, collaborative, and descriptive; (3) Contemporary with a value of 0.80 or valid. This shows that the material presented is actual, up-to-date, innovative, and accessible; and (4) Readability with a value of 0.91 or very valid. This shows that the writing used is easy to understand, in accordance with KBBI rules, appropriate physics terminology, and does not cause misunderstandings. In this indicator, the average validity value obtained is 0.83 or a very valid category. The average validity value per component is shown in the following graph.

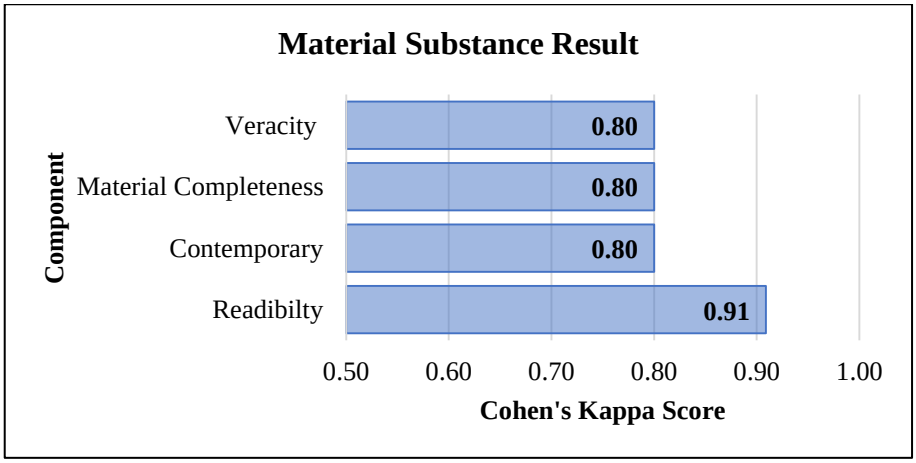

Fig. 3. Validity Test Results for Material Substance

B. Visual Communication Result

In the visual communication indicator there are six components, including: (1) Navigation with a value of 1.00 or very valid. This shows that the navigation presented by the e-module functions well; (2) Letters with a value of 1.00 or very valid. This shows that the composition of the letters used by the e-module is proportional; (3) Colors with a value of 1.00 or very valid. This shows that the composition of the colors used by the e-module is proportional; (4) Layout with a value of 1.00 or very valid. This shows that the structure and layout of the e-module are proportional; (5) Media with a value of 0.91 or very valid. This shows that the e-module presented is an interesting learning media to support learning; and (6) Animation with a value of 0.91 or very valid. This shows that the e-module presented has interesting animation to support learning. In this indicator, the average validity value is 0.97 or very valid category. The average value of validity per component is shown in the following graph.

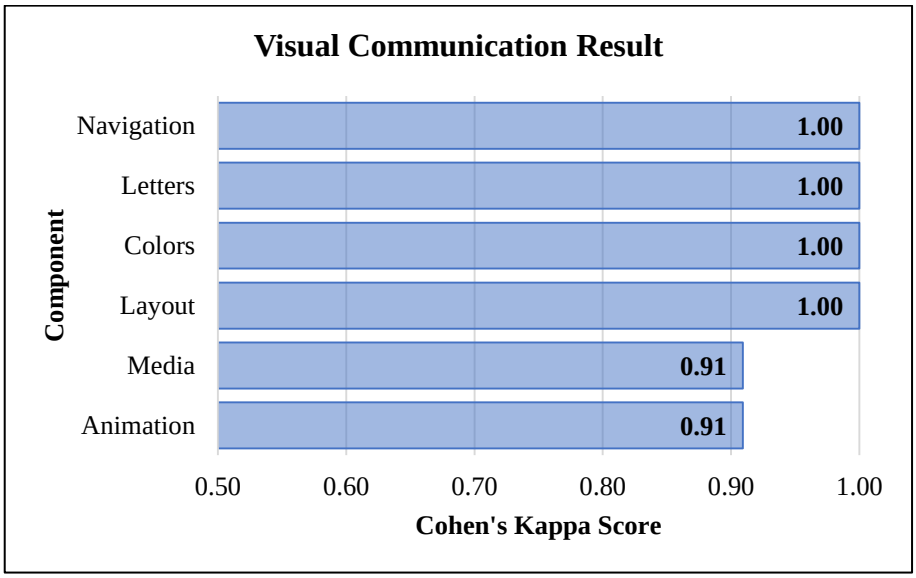

Fig. 4. Validity Test Results for Material Substance

C. Software Utilization Result

In the software utilization indicator, there are three components, including: (1) Interactive with a value of 1.00 or very valid. This shows that this AI-integrated e-module with PBL model provides feedback interaction from the system to the user; (2) Supporting Software with a value of 1.00 or very valid. This shows that this AI-integrated e-module with PBL model can be directly accessed via computer (PC) and smartphone; and (3) Originality with a value of 1.00 or very valid. This shows that this AI-integrated e-module with PBL model is an original work. Of the three components, the average validity value is 1.00 or very valid category. The average validity value per component is shown in the following graph.

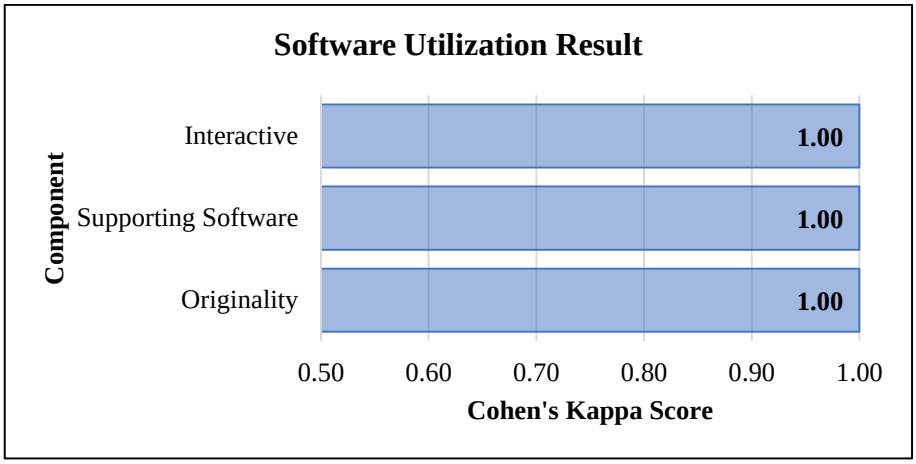

Fig. 5. Validity Test Results for Software Utilization

D. Problem Based Learning Model Result

The integration of PBL syntax on e-module. All components (Orienting to Problems, Organizing Learning, Guiding Inquiries, Developing Work, and Analyzing/Evaluating) consistently scored 0.91 (Very Valid). That means confirms the module faithfully follows PBL stages. The average validity value per component is shown in the following graph.

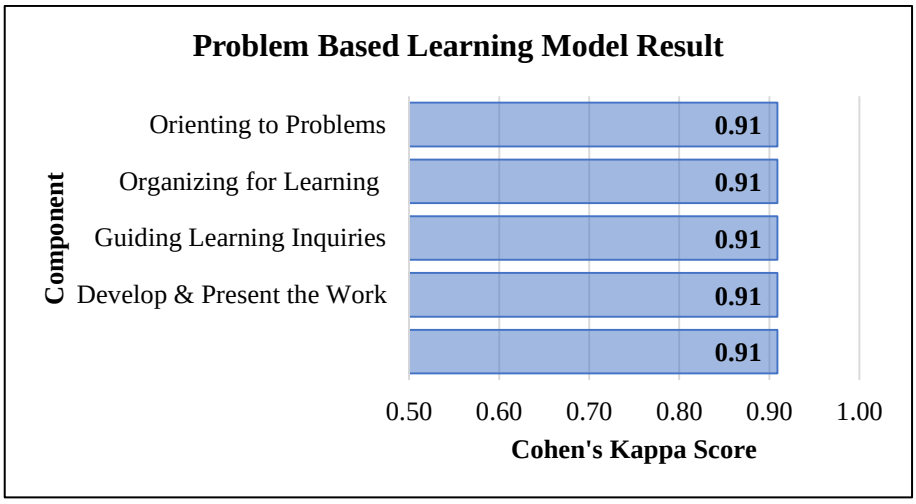

Fig. 6. Validity Test Results for Problem Based Learning Model

E. Learning Design Result

This extensive indicator includes 15 components (from Cover to Bibliography). The average was 0.92 (Very Valid). While most components scored very high, Learning Objectives and Material scored 0.80. The average validity value per component is shown in the following graph.

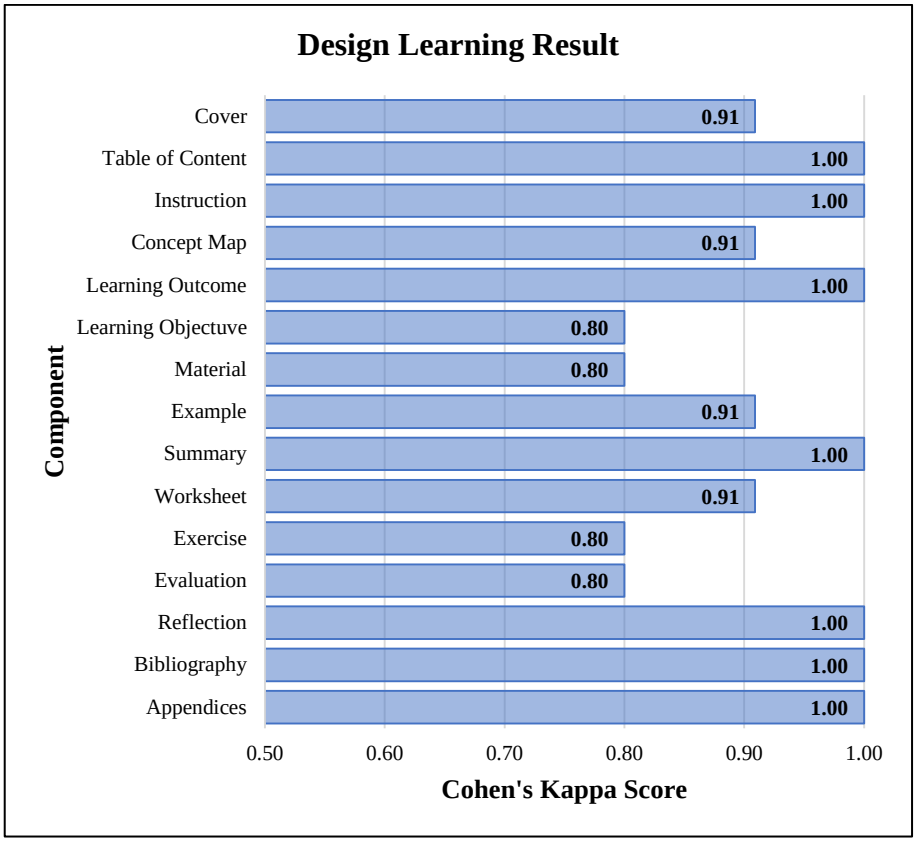

Fig. 7. Validity Test Results for Design Learning

F. Artificial Intelligence Integration

In the Artificial Intelligence (AI) Integration indicator, there are two components, namely: (1) Integration of Analysis and Feedback with a value of 0.91 or very valid. This shows that the e-module can analyze user answers and provide feedback; and (2) Integration of Interaction and Motivation with a value of 0.91 or very valid. This shows that the e-module can make learning more interactive and provide a pleasant learning experience. From these two components, the average validity value is 0.91 or the very valid category. The average validity value per component is shown in the following graph.

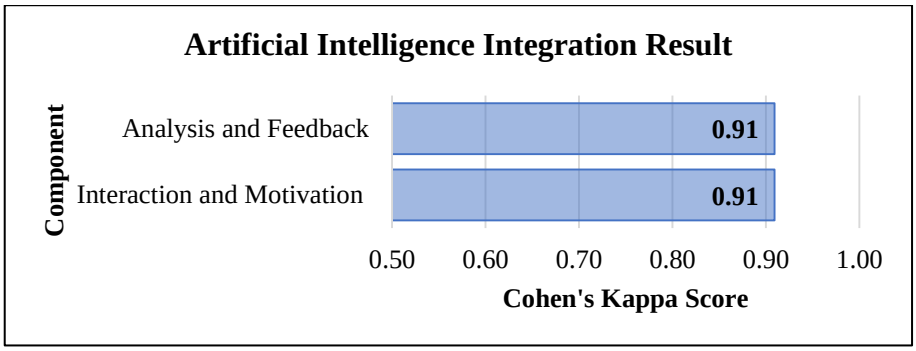

Fig. 8. Validity Test Results for Artificial Intelligence Integration

Based on these results, the overall average validity value of this AI-integrated e-module with PBL model is 0.92, categorized as very valid. This indicates that this AI-integrated e-module with PBL model is highly feasible for implementation. The average validity value per indicator is shown in the following graph.

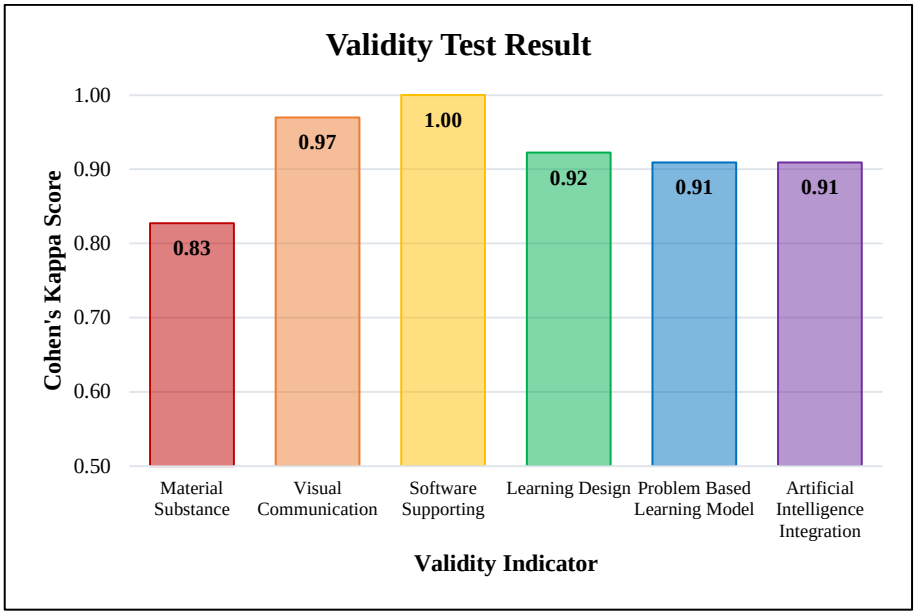

Fig. 9. Validity Test Result

Discussion

The comprehensive validation process, confirmed the high feasibility and quality of the e-module across all evaluated aspects. Based on the validators' input, comprehensive revisions were implemented to further improve the e-module's quality. These revisions included adding a scoring system to the critical thinking rubric, refining AI input and responses, adjusting practice questions to align with critical thinking indicators, diversifying learning activities with simulations and experiments, reorganizing worksheet activities according to PBL syntax, and improving the e-module's visual appeal. The validation data confirms that this AI-integrated e-module is not just a digital textbook, but a robust pedagogical tool. To understand the broader implications of these findings, it is valuable to situate them within recent research trends [21].

The strong score in Material Substance (0.83) ensures the module is scientifically sound. This aligns with Hariyanti et al. (2025), who argue that for the Merdeka Curriculum to succeed, teaching materials must be strictly aligned with contemporary contexts like renewable energy [22]. Furthermore, our focus on material completeness addresses a gap highlighted by Gunawan et al. (2023). In their work on PBL instruments, they found that integrating valid learning models with relevant local content is non-negotiable for fostering critical reasoning [23]. Our study extends this by proving that such rigor is achievable in a digital, AI-driven format for high school physics.

The perfect scores in Software Utilization (1.00) and high marks in Visual Communication support the meta-analysis findings of Fadillah et al. (2024). Their review of physics e-modules concluded that interactive digital media yields a significantly higher effect size on student learning compared to static materials [24]. Additionally, Virijai, Asrizal, and Festiyed (2022) emphasized that to prepare students for the Industrial Revolution 4.0, materials must go beyond text and integrate technology that stimulates higher-order thinking. Our module’s cross-platform compatibility ensures it meets these modern technical standards [25].

A critical success factor was the PBL Model validity (0.91). Ardha and Emiliannur (2025) recently demonstrated that PBL-integrated worksheets effectively facilitate creative thinking [26]. In their research complements this by showing that a similar PBL structure, when digitized, is equally valid for enhancing critical thinking. In research was highlighted by Hirahmah et al. (2024), following the PBL syntax, from problem orientation to evaluation, the module provides the necessary "scaffolding" for students to analyze complex problems, a need also identified in the bibliometric analysis [27].

Perhaps the most significant finding is the valid integration of AI (0.91). Hikmawati and Mohammad (2025) recently posited that Generative AI could revolutionize critical thinking education by offering complex scenarios and instant feedback [28]. Our validated module serves as a practical proof-of-concept for their theory. Moreover, the interactive nature of our AI features mirrors the work of Chen et al. (2023), who found that AI assistants (chatbots) could successfully support student success at scale [29]. Unlike generic chatbots, our AI is

contextually embedded within the renewable energy curriculum, providing targeted support that guides, rather than gives away, the answers [30].

IV. CONCLUSION

This research successfully developed and rigorously validated an AI-integrated e-module, specifically designed with a Problem-Based Learning (PBL) model, to cultivate critical thinking skills in 10th-grade high school students studying renewable energy. The comprehensive validation process, carried out by expert Physics Lecturers, consistently demonstrated the e-module's high feasibility and quality across all evaluated aspects. This confirms that the e-module provides scientifically accurate, comprehensive, and up-to-date content presented in an accessible manner, complemented by an engaging and interactive digital learning environment.

In essence, this AI-integrated e-module with a PBL model stands as a highly promising and feasible teaching material. Its innovative design and strong validation indicate its potential as a valuable resource for modern physics education, poised to significantly improve high school students' critical thinking abilities.

While the prototype is structurally sound, the next logical steps involve the Implementation and Evaluation phases of the ADDIE model. Future research will focus on deploying this module in real classrooms to empirically measure its impact on students' critical thinking scores through practically and effectiveness testing.

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