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Pathways to Scientific Literacy: A Preliminary Study on Developing Physics E-Modules to Foster Students' Critical Thinking Skills

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ABSTRACT

The integration of scientific literacy in physics learning is increasingly important to support students' critical thinking skills, particularly in abstract topics such as renewable energy. However, the availability of instructional materials that align with curriculum demands and students' characteristics remains limited. This study aims to conduct a comprehensive needs analysis as the initial stage in developing a scientific literacy-based physics e-module on renewable energy. The research employed a Research and Development (R&D) approach using the 4D model, focusing on the Define stage, which includes curriculum analysis, student analysis, concept analysis, and the formulation of instructional objectives. The study was conducted at SMAS Buqatun Mubaraqah, involving 25 tenth-grade students and one physics teacher. Data were collected through questionnaires, semi-structured interviews, and classroom observations, and analyzed using a descriptive mixed-methods approach. The results indicate a gap between curriculum expectations and existing instructional practices in supporting scientific literacy and critical thinking. Student analysis shows that visual (36%) and kinesthetic (32%) learning styles are dominant, while most students demonstrate moderate technology readiness (68%). In addition, concept analysis reveals that renewable energy topics involve abstract and dynamic processes that require visualization and interactive learning support. These findings provide a strong foundation for developing a scientific literacy-based physics e-module that aligns curriculum demands, student characteristics, and conceptual complexity to support meaningful learning and foster critical thinking skills.

INTISARI

Integrasi literasi sains dalam pembelajaran fisika semakin penting untuk mendukung kemampuan berpikir kritis peserta didik, khususnya pada topik abstrak seperti energi terbarukan. Namun, ketersediaan materi pembelajaran yang selaras dengan tuntutan kurikulum dan karakteristik peserta didik masih terbatas. Studi ini bertujuan untuk melakukan analisis kebutuhan komprehensif sebagai tahap awal dalam mengembangkan e-modul fisika berbasis literasi sains tentang energi terbarukan. Penelitian ini menggunakan pendekatan Penelitian dan Pengembangan (R&D) dengan model 4D, yang berfokus pada tahap

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Definisi, yang meliputi analisis kurikulum, analisis peserta didik, analisis konsep, dan perumusan tujuan pembelajaran. Studi ini dilakukan di SMAS Buqatun Mubaraqah, melibatkan 25 peserta didik kelas sepuluh dan seorang guru fisika. Data dikumpulkan melalui kuesioner, wawancara semi-terstruktur, dan observasi kelas, dan dianalisis menggunakan pendekatan metode campuran deskriptif. Hasil penelitian menunjukkan adanya kesenjangan antara harapan kurikulum dan praktik pembelajaran yang ada dalam mendukung literasi sains dan berpikir kritis. Analisis peserta didik menunjukkan bahwa gaya belajar visual (36%) dan kinestetik (32%) dominan, sementara sebagian besar peserta didik menunjukkan kesiapan teknologi yang moderat (68%). Selain itu, analisis konsep mengungkapkan bahwa topik energi terbarukan melibatkan proses abstrak dan dinamis yang membutuhkan visualisasi dan dukungan pembelajaran interaktif. Temuan ini memberikan landasan yang kuat untuk mengembangkan modul elektronik fisika berbasis literasi sains yang selaras dengan tuntutan kurikulum, karakteristik peserta didik, dan kompleksitas konseptual untuk mendukung pembelajaran yang bermakna dan menumbuhkan keterampilan berpikir kritis.

A. Introduction

The global transition toward sustainable energy has positioned renewable energy as a critical socio-scientific issue in 21st-century education (Ananiadou & Claro, 2009). As societies confront climate change, energy scarcity, and environmental degradation, physics education is increasingly expected to move beyond procedural knowledge toward the development of scientific literacy, enabling students to understand, evaluate, and apply scientific concepts to real-world problems (Rahmah et al., 2024; Ellianawati et al., 2025). Scientific literacy has been widely recognized as a fundamental competency for preparing students to make informed decisions and to participate responsibly in addressing complex global challenges. Within this context, renewable energy has become a core topic in secondary physics curricula, including in Indonesia's Kurikulum Merdeka for Grade X students.

Despite the importance of these topics, recent preliminary observations indicate a persistent gap in students' critical thinking skills. Many students struggle to analyze scientific data or provide evidence-based arguments, which are core components of both scientific literacy and critical thinking (Aris et al., 2024; Bramastia & Rahayu, 2023). This problem is often exacerbated by the lack of adaptive instructional materials. Conventional textbooks used in many schools, including SMAS Buqatun Mubaraqah, tend to present renewable energy in a static, descriptive manner, failing to engage students in the inquiry-based processes necessary to foster higher-order thinking (Faresta et al., 2024).

The rapid advancement of Information and Communication Technology (ICT) offers a transformative solution through the development of e-modules (Cynthia et al., 2023; Karnando et al., 2023). Previous studies have shown that digital-based learning can enhance student engagement and facilitate self-regulated learning (Yosa et al.,

2025). However, many existing e-modules remain limited to static PDF-based textbooks, which lack the interactivity, pedagogical tools, and learning activities shown to enhance student engagement and motivation when web-based materials are implemented through one-to-one Chromebook integration (Albataineh et al., 2024).

To address this gap, it is imperative to first conduct a systematic analysis through the define phase of the 4D development model (Define, Design, Develop, and Disseminate) to establish a rigorous pedagogical foundation for a scientific literacy-based physics e-module. This phase is critical for identifying why existing resources fail to integrate scientific literacy indicators explaining phenomena scientifically, evaluating scientific inquiry, and interpreting evidence into a structured digital framework (Arafah et al., 2024). By prioritizing this analytical stage, the research ensures that the subsequent instructional design is directly informed by a comprehensive assessment of curriculum demands and student characteristics.

Despite the growing number of studies on digital learning and physics e-modules, several important gaps remain in the existing literature. Most previous research has primarily focused on evaluating the effectiveness of completed instructional products, while comparatively limited attention has been given to the preliminary needs analysis stage within research and development frameworks. As a result, the systematic alignment between curriculum demands, students' characteristics, and technological constraints is often insufficiently explored prior to instructional design (Branch & Kopcha, 2014).

Furthermore, existing studies tend to examine scientific literacy, students' learning styles, and technology readiness as separate variables, rather than integrating these dimensions as a coherent basis for developing digital learning materials. Scientific literacy in this study refers to students' ability to apply scientific knowledge to explain phenomena, evaluate scientific inquiry, and interpret data and evidence in real-world contexts. This study adopts the scientific literacy framework proposed by PISA, which consists of three core competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically.

Addressing these gaps, the present study contributes a comprehensive needs analysis grounded in the Define stage of the 4D development model to inform the development of a scientific literacy-based physics e-module on renewable energy. This study extends prior research through an integrative approach aligning scientific literacy competencies, students' learning profiles, and technology readiness to support the systematic development of critical thinking skills within a formal school context. In addition, this study specifically addresses the limited integration of scientific literacy competencies in physics e-module development within Chromebook-supported learning environments at the needs analysis stage (van Merriënboer & Kirschner, 2017).

In this context, the urgency of this development is further underscored by the distinctive constraints of Chromebook-supported smart classroom environments. While mobile-based learning has been extensively examined in the literature, far less attention has been devoted to instructional resources designed for formal school settings that operate under strict device regulations and controlled digital ecosystems. In such contexts, the pedagogical potential of Chromebooks often remains underutilized due to the absence of structured, curriculum-aligned digital materials that explicitly integrate scientific literacy competencies.

By systematically identifying these technological and pedagogical constraints during the Define stage, the present study establishes a critical foundation for the development of a contextualized physics e-module grounded in scientific literacy. Within this framework, scientific literacy serves as a pathway for developing students' critical thinking skills, as it requires learners to engage in explaining scientific phenomena, critically evaluating inquiry processes, and interpreting evidence in a reasoned and reflective manner.

This approach is essential to fully leverage the affordances of Chromebooks and to transform them from mere access devices into purposeful instructional tools that support inquiry-based learning, evidence-based reasoning, and the meaningful development of students' critical thinking skills.

B. Method

This study employed a Research and Development (R&D) approach by adopting the 4D development model, which consists of Define, Design, Develop, and Disseminate stages (Thiagarajan et al., 1974). The present research was limited to the Define stage as a preliminary study aimed at identifying instructional needs, analyzing students' characteristics, and examining conceptual challenges as a foundation for the subsequent design and development of a scientific literacy-based physics e-module. Focusing on this stage enables a systematic identification of curriculum demands, students' characteristics, and conceptual challenges specifically related to renewable energy learning, which are essential prior to instructional design and product development.

The research was conducted at SMAS Buqatun Mubaraqah, Makassar. The participants of this study consisted of 25 tenth-grade students and one physics teacher. The students were selected using a purposive sampling technique, focusing on one class (n = 25) that was actively engaged in a Chromebook-supported smart classroom environment. All students in the selected class were included as research participants. The physics teacher was selected based on their direct involvement in physics instruction and curriculum implementation.

Data were collected using a triangulation approach to enhance the credibility of the findings. This involved semi-structured interviews with the physics teacher and

diagnostic surveys administered to the 25 students. The interviews aimed to explore curriculum implementation, instructional challenges, and the availability of learning resources. Meanwhile, the questionnaires were used to obtain quantitative data on students' learning styles and levels of technology readiness within a Chromebook-supported smart classroom environment. In addition, classroom observations and documentation were conducted to support and validate the findings from the primary data sources.

Several research instruments were used in this study, including an interview guide, a learning style questionnaire, a technology readiness questionnaire, and observation sheets. The learning style questionnaire was adapted from the VAK Learning Style Questionnaire developed by Victoria Chislett, with minor contextual modifications to suit the study setting. Technology readiness was measured using the Technology Readiness Index 2.0 developed by Parasuraman. These instruments were designed to capture data related to curriculum needs, students' characteristics, and conceptual challenges in renewable energy topics. A summary of the research instruments is presented in Table 1.

Table 1. Research Instruments

No.	Instrument	Aspect Measured	Data Type	Respondent
1	Interview guideline	Curriculum implementation and instructional challenges	Qualitative	Physics teacher
2	Learning style questionnaire	Students' learning style profiles	Quantitative	Tenth-grade students
3	Technology readiness questionnaire	Students' level of technology readiness	Quantitative	Tenth-grade students
4	Observation sheet	Learning environment and facility conditions	Qualitative	Researcher

The collected data were analyzed using a descriptive mixed-methods approach. Qualitative data obtained from interviews and observations were analyzed using thematic analysis, which involved three main steps: (1) open coding to identify meaningful data segments, (2) categorization to group similar codes into broader categories, and (3) theme development to generate overarching themes representing students' needs, instructional challenges, and technological constraints. Quantitative data from questionnaires were analyzed using descriptive statistics (e.g., percentages) to summarize students' learning styles and technology readiness levels.

The research procedures followed the systematic steps of the Define stage in the 4D development model. The procedures began with curriculum analysis to examine the alignment between learning outcomes and existing instructional materials. This was followed by learner analysis to identify students' learning profiles and technology readiness. Subsequently, a concept analysis was conducted to identify key renewable energy concepts that require visualization and inquiry-based learning. The final step involved formulating learning objectives based on scientific literacy competencies to

systematically foster students' critical thinking skills. The outputs of the Define stage in this study include: (1) identification of curriculum-aligned learning needs, (2) profiles of students' learning styles and technology readiness, (3) mapping of key renewable energy concepts requiring visualization and inquiry-based learning, and (4) formulation of scientific literacy-based learning objectives to support critical thinking development.

C. Result and Discussion

The results of this study are presented and discussed in accordance with the four main objectives of the needs analysis conducted in the Define stage of the 4D development model, namely: curriculum analysis, student analysis, concept analysis, and the formulation of learning objectives (Winarni, 2018). Data were obtained through questionnaires, interviews, classroom observations, and documentation, and were analyzed using both quantitative and qualitative approaches.

Curriculum Analysis

The findings indicate that the Capaian Pembelajaran (CP) in the Kurikulum Merdeka for Fase E explicitly emphasizes the development of scientific literacy and scientific inquiry competencies. This implies that physics learning is expected to move beyond content mastery toward competency-based learning, particularly in analyzing real-world problems related to renewable energy.

However, the findings from classroom observations and interviews reveal a significant gap between curriculum expectations and classroom practices. Although the curriculum mandates inquiry-based and student-centered learning, instruction remains predominantly conventional and relies heavily on limited printed textbooks. These materials tend to present content in a static and descriptive manner, which does not adequately support the development of higher-order thinking skills (Aldilla et al., 2023). This condition is consistent with previous studies indicating that traditional instructional materials often fail to facilitate scientific literacy and critical thinking development (OECD, 2023).

Furthermore, limited access to instructional media, such as projectors, restricts teachers' ability to visualize abstract and dynamic processes, including photovoltaic mechanisms and wind turbine operations. As a result, students experience difficulties in connecting theoretical concepts with real-world phenomena.

Interestingly, the analysis also reveals a strategic opportunity. The school is equipped with a Smart Class facility that includes a Smart TV and Chromebooks. However, the absence of structured, curriculum-aligned digital learning materials results in the underutilization of these technological resources. This finding highlights a critical mismatch between technological infrastructure and pedagogical implementation.

Therefore, these results suggest that the development of a scientific literacy-based physics e-module specifically designed for Chromebook-supported environments is essential. Such an e-module can bridge the gap between curriculum demands, classroom realities, and available technological resources while supporting inquiry-based and critical thinking-oriented learning.

Student Analysis

This section presents the results of the student analysis, focusing on learning preferences and their implications for physics learning. The findings indicate that visual learning is the most dominant style (36%), followed by kinesthetic (32%) and auditory (16%) learning styles, while mixed learning styles represent smaller proportions. As illustrated in Figure 1, this distribution shows that a majority of students tend to rely on visual processing and active engagement in understanding physics concepts.

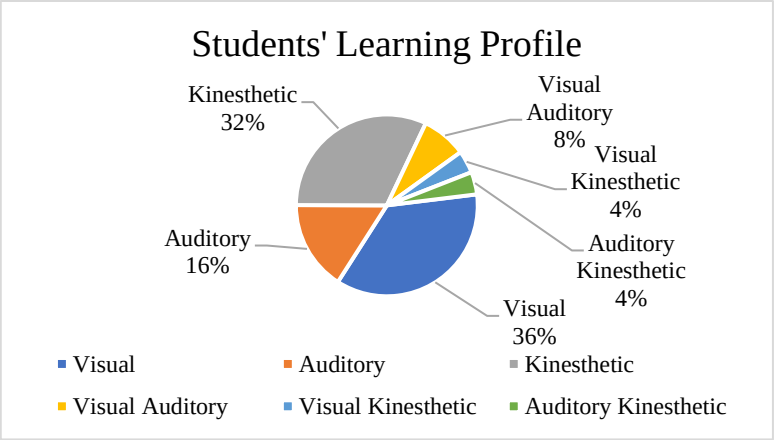

Figure 1. Students' Learning Profile Distribution

The dominance of the visual learning style indicates that a substantial proportion of students rely on visual representations to process information. This suggests that students' conceptual understanding is closely linked to the availability of instructional materials that present abstract concepts in visual forms. In physics learning, where many concepts involve invisible or dynamic processes, limited visualization may hinder students' ability to construct meaningful understanding. Therefore, the distribution not only reflects learning preferences but also points to potential challenges in conceptual comprehension when visual support is insufficient. Visual representations, such as diagrams, graphs, and animations, can assist students in organizing information, identifying relationships between variables, and linking abstract concepts to observable phenomena (Tippett, 2016).

In addition to visual learning, the relatively high proportion of kinesthetic learners (32%) indicates that many students benefit from active engagement in the learning process. This finding suggests that learning experiences involving

exploration and interaction with phenomena are important for supporting conceptual understanding. Such engagement can facilitate deeper cognitive processing and contribute to the development of higher-order thinking skills (Hermansyah et al., 2021).

Although auditory and mixed learning styles constitute smaller proportions, their presence highlights the diversity of students' learning preferences. This variation indicates that a single mode of instruction may not adequately support all learners. Instead, providing multiple forms of representation and varied learning experiences is essential to accommodate different learning needs and promote more inclusive learning processes.

Taken together, these findings indicate that students' learning characteristics have direct implications for instructional design. The dominance of visual and kinesthetic preferences suggests that learning resources should emphasize both visual representation and active engagement. In this study, these characteristics provide an empirical basis for developing physics e-modules that integrate visual elements and interactive activities, particularly for supporting the understanding of abstract concepts such as renewable energy.

Within the framework of scientific literacy, these learning characteristics are closely related to the development of key competencies, including explaining scientific phenomena, evaluating inquiry processes, and interpreting data and evidence. Learning experiences that combine visual representation and active engagement can support students in understanding concepts, analyzing relationships, and constructing evidence-based reasoning. Thus, the results not only describe students' learning preferences but also establish a foundation for designing instructional materials that systematically support scientific literacy and the development of critical thinking skills.

In terms of technology readiness, the results indicate that the majority of students are at a moderate level (68%), followed by high (28%) and very high (4%) levels, with no students categorized as low. As presented in Figure 2, this distribution suggests that students possess foundational digital skills that enable them to participate in technology-enhanced learning environments.

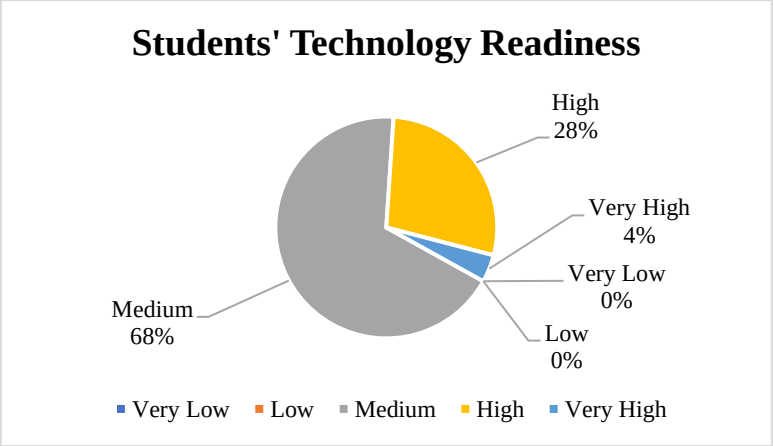

Figure 2. Students' Technology Readiness Distribution

The predominance of moderate technology readiness indicates that most students are familiar with basic digital tools and are capable of accessing online learning platforms and educational applications. However, students in this category may still encounter challenges when interacting with more complex digital learning environments. These challenges may include navigating multi-layered interfaces, interpreting interactive visualizations, and independently engaging with simulation-based learning tools. Such findings suggest that, although students demonstrate basic operational skills, they may still require structured guidance to fully utilize digital learning resources.

In contrast, the presence of students with high and very high levels of technology readiness reflects a strong potential for engaging with more advanced digital learning environments. These students are likely able to explore digital features more independently and adapt more quickly to technology-integrated instruction. This condition may also support collaborative learning processes, where students with higher technological proficiency can contribute to peer-assisted learning (Zamiri & Esmaeili, 2024).

Furthermore, the absence of students in the low readiness category indicates that technological barriers are not a primary constraint in this context. However, the dominance of moderate readiness highlights the need for learning environments that are accessible and supportive. This implies that digital instructional materials should be designed with clear navigation structures and guided learning processes to ensure effective student interaction.

Overall, these findings indicate that students' level of technology readiness provides a supportive foundation for the integration of digital learning tools. At the same time, the variation in readiness levels suggests the importance of designing learning experiences that are both accessible and capable of gradually supporting students toward more independent and interactive learning. Within the framework of scientific literacy, such conditions are essential for enabling students to engage in

inquiry processes, interpret data, and construct evidence-based reasoning in a structured digital environment (Handog & Aliazas, 2024; Sujanem et al., 2020).

Concept Analysis

The concept analysis began by mapping the fundamental principles of renewable energy as mandated by the Kurikulum Merdeka Fase E. This process aimed to identify conceptual bottlenecks where students frequently encounter difficulties in understanding abstract physics mechanisms (Maisaroh & Sulisworo, 2025). Based on preliminary classroom observations and interviews with physics teachers, it was found that concepts such as energy transformation and the efficiency of power plants are among the most challenging topics for tenth-grade students. These concepts involve complex and largely invisible physical processes that are difficult to illustrate using the school's currently available learning resources, which are limited to static textbooks and classrooms with restricted projection facilities. As a result, students often struggle to connect theoretical explanations with observable phenomena.

To address these challenges, the concept analysis focused on organizing renewable energy content into three integrated conceptual pillars: energy sources, energy conversion mechanisms, and socio-environmental impacts. Structuring the content in this way helps students understand renewable energy as an interconnected system rather than a collection of isolated formulas (Abdurrahman et al., 2023). through this conceptual structure, students are gradually guided from identifying different forms of energy to analyzing how environmental variables, such as wind speed or solar radiation intensity, influence energy production in renewable power systems. This systematic progression supports students in building a coherent conceptual framework that forms the basis for deeper analytical thinking.

In addition to the conceptual structure, the design of learning representations was aligned with the results of the student analysis, which showed a dominance of visual (36%) and kinesthetic (32%) learning preferences. Consequently, abstract processes such as electron flow in photovoltaic cells or the aerodynamic motion of wind turbine blades were prioritized for digital visualization. By transforming these invisible mechanisms into dynamic visual representations through animations and interactive models, the e-module provides cognitive scaffolding that helps students visualize complex physical processes. Such visual support reduces cognitive load and enables students to link theoretical explanations with observable patterns, thereby strengthening their conceptual understanding of renewable energy systems (Putri et al., 2025; Yuningsih et al., 2025).

Furthermore, the concept analysis incorporated the competencies of scientific literacy as a pedagogical framework for delivering these concepts. The competencies of explaining scientific phenomena, evaluating scientific inquiry, and interpreting scientific data were intentionally embedded into learning activities to stimulate

students' critical thinking skills. For example, the concept of energy efficiency is not presented merely as a mathematical ratio but as an evidence-based inquiry task. Students are required to interpret data, compare energy output patterns, and evaluate the effectiveness of different renewable technologies. Through these activities, students practice understanding scientific information, analyzing evidence, generating scientific inferences, and explaining their reasoning based on empirical data. This learning design encourages students to move beyond memorizing formulas toward engaging in analytical and evaluative thinking processes (Syafitri & Syafriani, 2023).

Finally, the synthesis of this concept analysis informed the design of a digital learning environment tailored to the Chromebook-supported Smart Class system. Considering students' moderate technology readiness and the school's restricted internet access policy, the e-module was designed as a self-contained learning resource. All interactive simulations, animations, and visual datasets are embedded directly within the module, allowing students to access learning materials without relying on external websites. This design ensures that students can still engage in data interpretation, conceptual explanation, and problem-solving activities even within a controlled technological environment. The systematic mapping between conceptual challenges, digital learning solutions, and critical thinking stimuli is summarized in Table 2. This mapping ensures that each abstract concept is paired with a specific digital representation designed to promote higher-order thinking within the Chromebook-based learning environment.

Table 2. Conceptual Mapping of Physics E-Module to Stimulate Critical Thinking

Core Concept	Abstract Challenge	Digital Solution	Critical Thinking Stimulus
Energy Forms & Transformation	Difficulty visualizing invisible energy shifts.	Interactive animations and dynamic flowcharts developed using Canva and supported by physics simulations from PhET Interactive Simulations.	**Analysis:** Identifying energy losses during energy conversion processes
Mechanisms of Power Plants	Limited access to the internal mechanisms of real-world renewable energy systems, particularly Solar Power Plants (PLTS) and Wind Power Plants (PLTB)	Interactive simulations and virtual component exploration.	**Evaluation:** Comparing the efficiency of different renewable technologies.
Energy Efficiency	Difficulty understanding how environmental variables influence energy output..	Data-driven scenarios with variable manipulation.	**Inference:** Predicting energy output based on changing environmental conditions.

Socio-Environmental Impact	Disconnection between physics concepts and real-world consequences.	Evidence-based case studies with integrated visual data	**Problem Solving:** Proposing solutions to local energy challenges using scie.ntific evidence.

Formulating Learning Objectives

The instructional objectives were formulated based on the three core competencies of scientific literacy as defined by OECD, namely explaining scientific phenomena, evaluating and designing scientific inquiry, and interpreting data and scientific evidence (Santhalia & Yuliati, 2021). These competencies were not only used as a framework for organizing content but were also theoretically aligned with critical thinking frameworks, particularly those encompassing understanding, analysis and evaluation, inference, explanation, and problem solving. This alignment ensures that each learning objective systematically contributes to the development of higher-order thinking skills.

In the Define stage, the formulation of instructional objectives involved synthesizing findings from curriculum analysis, student characteristics, and concept analysis. The objectives were intentionally refined to move beyond basic content mastery and instead function as structured stimuli for critical thinking. By aligning the Capaian Pembelajaran (CP) of the Kurikulum Merdeka with students' dominant visual–kinesthetic learning preferences, the learning objectives were designed to integrate conceptual understanding with active cognitive engagement through scientific literacy practices.

First, students are expected to explain renewable energy phenomena scientifically. This objective trains students to understand and articulate the underlying physics concepts of energy transformation by utilizing high-fidelity animations embedded in the e-module (Alhusni et al., 2025). Through this process, students develop their ability to interpret scientific information and construct logical explanations, which correspond to the understanding and explanation components of critical thinking.

Second, students are required to evaluate and design scientific inquiry. Through interactive simulations within the Chromebook-supported environment, students manipulate variables such as solar intensity and wind speed and assess their impact on energy output (Wang et al., 2015). This activity engages students in analyzing relationships between variables and evaluating the validity of simulated results, thereby directly fostering analytical and evaluative thinking skills (Trúsiková & Velmovská, 2022).

Finally, students are expected to interpret data and scientific evidence. They analyze digital datasets and graphical representations provided within the self-contained e-module to identify patterns and draw evidence-based conclusions about

the efficiency and sustainability of different energy sources. This process explicitly develops students' ability to generate scientific inferences, as conclusions must be logically derived from empirical data.

As a concrete outcome of this formulation stage, the following specific learning objectives were established as the foundation for the e-module development:

1. Competency 1 (Explaining Phenomena): Students are able to analyze the mechanical flow of energy in Solar Power Plants (PLTS) and Wind Power Plants (PLTB) systems using interactive 3D-integrated animations.
2. Competency 2 (Evaluating Inquiry): Students are able to evaluate the impact of environmental variables (e.g., solar intensity and wind speed) on energy output through interactive simulation-based investigations.
3. Competency 3 (Interpreting Evidence): Students are able to infer the most efficient energy solution for specific geographical conditions by interpreting digital datasets and graphical representations provided in the module.

Through these clearly defined objectives, the e-module is positioned not merely as a digital learning resource, but as a structured inquiry-based platform that systematically promotes students' critical thinking skills within the context of renewable energy learning (Purwaningsih et al., 2025).

D. Conclusion

This study conducted a comprehensive needs analysis within the Define stage of the 4D development model to inform the development of a scientific literacy-based physics e-module on renewable energy. The findings reveal a critical misalignment between curriculum expectations and existing instructional practices, particularly in supporting scientific literacy and critical thinking.

Empirical results show that students predominantly exhibit visual (36%) and kinesthetic (32%) learning preferences, alongside moderate levels of technology readiness (68%). These characteristics indicate that while students are capable of engaging in technology-enhanced learning, they require structured and visually supported instructional environments to fully optimize their learning processes.

In addition, the analysis highlights that renewable energy concepts involve abstract and dynamic processes that demand interactive visualization and inquiry-based learning approaches. The integration of scientific literacy competencies explaining phenomena, evaluating inquiry, and interpreting evidence provides a coherent pedagogical framework for designing such learning environments.

Overall, this study demonstrates that aligning curriculum demands, learner characteristics, conceptual complexity, and scientific literacy competencies is essential for developing effective digital learning materials. This alignment not only supports meaningful conceptual understanding but also serves as a strategic pathway for fostering students' critical thinking skills in physics education.

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