

Development of a Science Literacy-Based Physics E-Module on Renewable Energy

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Abstract. This paper reports the development of a science literacy-based physics e-module on renewable energy for Grade 10 (Phase E) students. The development was guided by the Define, Design, and Develop stages of the 4D model. The Define stage was informed by curriculum, learner, concept, and needs analyses, including findings from a previously published needs analysis at the research site. The needs analysis indicated a demand for more interactive digital learning, stronger visualization of abstract renewable-energy processes, explicit science literacy activities, and learning tasks that engage higher-order reasoning. The Design stage translated these requirements into a learning architecture that integrates three science literacy competencies; explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically with problem-based learning activities and multimedia presentation informed by the Cognitive Theory of Multimedia Learning. The Develop stage produced an e-module containing explanatory text, illustrations, videos, interactive activities, electronic student worksheets (LKPD), exercises, and evaluation tasks. Expert validation produced an average Aiken's V of 0.87, while practitioner assessment yielded an overall practicality score of 84.58%, categorized as very practical. The resulting product provides a needs-driven architecture in which scientific phenomena, inquiry, evidence interpretation, and contextual problem solving are embedded in the learning sequence. The findings establish the initial quality of the developed product and provide a basis for subsequent implementation and research on students' critical thinking skills.

Keywords: *Physics E-Module; Science Literacy; Renewable Energy*

INTRODUCTION

Physics education is expected not only to develop conceptual understanding but also to prepare students to reason with evidence, interpret scientific information, evaluate claims, and formulate solutions to real-world problems. These competencies are central to science literacy because scientific literacy requires learners to use scientific knowledge to explain phenomena, engage with scientific inquiry, and interpret evidence in science-related contexts [1], [2]. In physics, these competencies become particularly important when learning involves phenomena that cannot be fully understood through descriptive text alone.

Renewable energy provides a relevant context for such learning because it connects physics concepts with environmental, technological, and societal issues. Students need to understand energy sources and transformations while also considering evidence, technological alternatives, efficiency, and environmental consequences. Previous studies have demonstrated the potential of digital physics materials, science-literacy-oriented modules, and problem-based e-learning resources to support higher-order learning [3] [8]. However, the existence of a digital format does not by itself ensure meaningful learning.

The development reported in this paper builds on a needs analysis conducted at the same research site and previously published as a preliminary study [9]. That study identified a gap between curriculum expectations and existing learning practices in supporting science literacy and critical-thinking processes. Visual (36%) and kinesthetic (32%) learning preferences were the dominant profiles, while 68% of students demonstrated moderate technology readiness. Renewable-energy concepts involving energy transformation and power-generation processes were also identified as conceptually difficult and in need of stronger visualization and interactive support [9]. These findings provided an empirical basis for translating learner and context characteristics into concrete instructional-design requirements.

The design of the e-module was also informed by the Cognitive Theory of Multimedia Learning (CTML). CTML emphasizes that meaningful multimedia learning depends on the processing and integration of verbal

and visual representations under limited working-memory capacity [10]. Therefore, multimedia elements should not be added merely for attractiveness; they should support the organization and interpretation of relevant scientific information. In the present development, science literacy determines the nature of cognitive activities, problem-based learning provides a contextual learning sequence, and CTML informs the presentation of text and visual information. Broader research on digital learning materials, technology integration, and instructional design similarly emphasizes the alignment of digital components with pedagogical purposes [11]-[16].

A further consideration is the relationship between science literacy and higher-order reasoning. Science literacy activities require students to understand phenomena, examine information and evidence, interpret data, evaluate inquiry, and formulate explanations or solutions [2], [13]. Accordingly, the e-module was designed to provide opportunities for these processes through contextual renewable-energy problems rather than treating higher-order reasoning as a separate assessment component.

Although previous studies have reported digital and science literacy oriented learning materials, relatively limited attention has been given to explicitly documenting how identified learner needs are translated into a coherent renewable energy e-module architecture that integrates science literacy, problem-based learning, and multimedia principles. This paper addresses this gap by documenting the needs driven design and development of the e-module and by reporting expert and practitioner evaluation of the resulting product. The objective was to develop a Grade 10 (Phase E) physics e-module on renewable energy in which science literacy competencies, contextual problems, multimedia representations, and learner characteristics are systematically translated into product features, and to evaluate its validity and practicality.



Figure 1. Needs driven development pathway from Define to Design and Develop

METHODS

Research Design and Scope

This study employed a research and development (R&D) approach adapted from the 4D development model proposed by Thiagarajan et al. [17]. The model consists of Define, Design, Develop, and Disseminate stages. This paper focuses on the development process through the Define, Design, and Develop stages, including expert validation and practitioner practicality assessment. The research was conducted at SMAS Buqatun Mubarakah, Makassar, in Grade 10 (Phase E) physics during the first semester of the 2025/2026 academic year.

Define Stage

The Define stage synthesized four sources of development requirements: curriculum analysis, learner-characteristics analysis, concept analysis, and learning-needs analysis. The previously published needs analysis at the study site involved classroom observation, teacher input, student diagnostic data, learning-style information, and technology-readiness data [9]. These findings were treated as design requirements rather than as new outcome data in the present paper.

Curriculum and task analysis positioned renewable energy within Grade 10 (Phase E) physics and identified the learning demand to connect conceptual knowledge with scientific reasoning. Concept analysis organized the topic around energy problems, renewable and nonrenewable sources, types of renewable energy, principles of renewable-energy systems, energy conversion, ecological and social impacts, and possible solutions. Particular attention was given to energy transformation and power-generation efficiency because these processes involve abstract mechanisms that benefit from visual and interactive representation [9].

The Define stage also translated the learner profile into design and usability requirements. The prominence of visual and kinesthetic preferences suggested the need for multiple representations and opportunities for active engagement, while the predominance of moderate technology readiness required clear navigation, guided interaction, and a manageable digital interface. These requirements were subsequently connected to the learning architecture in the Design stage.

Table 1. Translation of documented needs into e-module design requirements

Design requirement	Need identified	Planned product feature
Multiple representations and active	Visual (36%) and kinesthetic (32%)	Illustrations, diagrams, videos,

engagement	profiles	interactive tasks, electronic worksheets
Simple and guided digital interaction	Technology readiness predominantly moderate (68%)	Consistent navigation, short instructions, structured sequence
Enhanced visualization of mechanisms	Abstract and dynamic renewable energy processes	Energy flow diagrams, process illustrations, contextual videos
Scientific reasoning embedded in tasks	Need for explicit science literacy activities	Phenomenon explanation, inquiry, and evidence interpretation
Problem centered learning sequence	Need for higher order and contextual learning	Renewable energy problems, investigation prompts, solution tasks

Design Stage

The Design stage translated the requirements into a learning architecture consisting of learning objectives, content sequence, science literacy activities, problem-based learning activities, multimedia representations, electronic worksheets, exercises, and evaluation. The design was organized around three science literacy competencies: explaining phenomena scientifically; evaluating and designing scientific inquiry; and interpreting data and evidence scientifically [2]. These competencies were embedded in the learning sequence rather than presented as separate labels.

Problem-based learning (PBL) was integrated to provide a contextual structure for the science literacy activities. Renewable-energy issues were formulated as problems that require students to identify relevant information, examine evidence, consider possible explanations, and propose contextually appropriate solutions. Thus, PBL functions as the learning pathway, while science literacy defines the cognitive and scientific practices that students are expected to perform.

CTML was used to guide the presentation layer. Explanatory text was paired with relevant illustrations, diagrams, and videos when visual representations could clarify a process or relationship. Interactive activities and electronic worksheets were positioned after or alongside relevant conceptual explanations so that students could use information rather than merely read it. Unnecessary decorative elements were minimized to maintain coherence between the representation and the intended learning task [10].

Table 2. Alignment of science literacy competencies with learning activities and intended cognitive processes.

Science literacy competency	Learning activity	Intended critical thinking process
Explaining phenomena scientifically	Observe a renewable-energy phenomenon; identify relevant concepts; construct an explanation	Problem understanding and explanation
Evaluating and designing scientific inquiry	Examine a contextual question; determine information needed; evaluate procedures or alternatives	Analysis and problem-solving strategy
Interpreting data and evidence scientifically	Read tables/graphs or presented evidence; compare information; draw a conclusion	Inference and evidence-based explanation

Develop Stage

The Develop stage converted the design specifications into the e-module prototype. The product was organized as a sequence of learning meetings containing orientation and prior knowledge activation, conceptual explanations, visual representations, contextual problems, science literacy activities, electronic worksheets, exercises, and evaluation. The content focused on renewable energy concepts and was written for Grade 10 (Phase E) learners.

The resulting product combined several forms of representation: explanatory text for conceptual grounding, illustrations and diagrams for processes that are difficult to observe directly, videos or other multimedia elements for dynamic phenomena, interactive activities for learner engagement, and electronic worksheets for structured inquiry and problem solving. The sequence was designed so that multimedia representations served an instructional function and were connected to scientific reasoning tasks. Figure 2 summarizes the resulting product architecture.

The development process therefore produced more than a digital copy of a conventional textbook. Its defining characteristic is the integration of science literacy activities into the instructional sequence. Each major content component is connected to an activity requiring students to explain a phenomenon, investigate a question, interpret evidence, or formulate a solution. The product architecture also reflects the learner and technology characteristics identified during the Define stage.

Product quality was evaluated through expert validation and practitioner practicality assessment. Three experts assessed a 40 items validation instrument covering content (11 items), presentation (13 items), language (5 items), and graphics (11 items). Content validity was quantified using Aiken's V [18]. Based on the validity criterion adopted in this study, coefficients above 0.80 were interpreted as high validity. Practicality was assessed by 10 physics teachers from senior high schools in South Sulawesi using a Likert scale questionnaire covering the same four aspects. The resulting scores were converted to percentages and interpreted using the practicality criteria adopted from Riduwan [19]. The controlled student learning outcome test was outside the scope of this proceeding paper.

RESULTS AND DISCUSSION

Results

Development Requirements

The development process produced a traceable set of requirements linking the learning context to the e-module features. The Define stage identified curriculum demands, learner characteristics, technology readiness conditions, and the conceptual characteristics of renewable-energy learning as the main bases for product design. The previously published needs analysis identified a demand for interactive digital learning, stronger visualization of abstract and dynamic renewable energy processes, explicit science literacy activities, and higher-order learning tasks [9].

The resulting design requirements were translated into specific product features. Learner and technology characteristics were addressed through varied representations, guided interaction, clear navigation, and a structured sequence. The content requirements were addressed through contextual renewable energy problems and activities requiring students to use scientific information and evidence.

Science Literacy-Based Physics E-Module Architecture

The developed e-module was organized around three science literacy competencies: explaining phenomena scientifically; evaluating and designing scientific inquiry; and interpreting data and evidence scientifically [2]. These competencies were embedded in the learning sequence rather than presented as separate labels. The product also incorporated problem-based learning activities and digital learning components consisting of explanatory text, illustrations and diagrams, videos, interactive activities, electronic student worksheets (LKPD), exercises, and evaluation tasks.

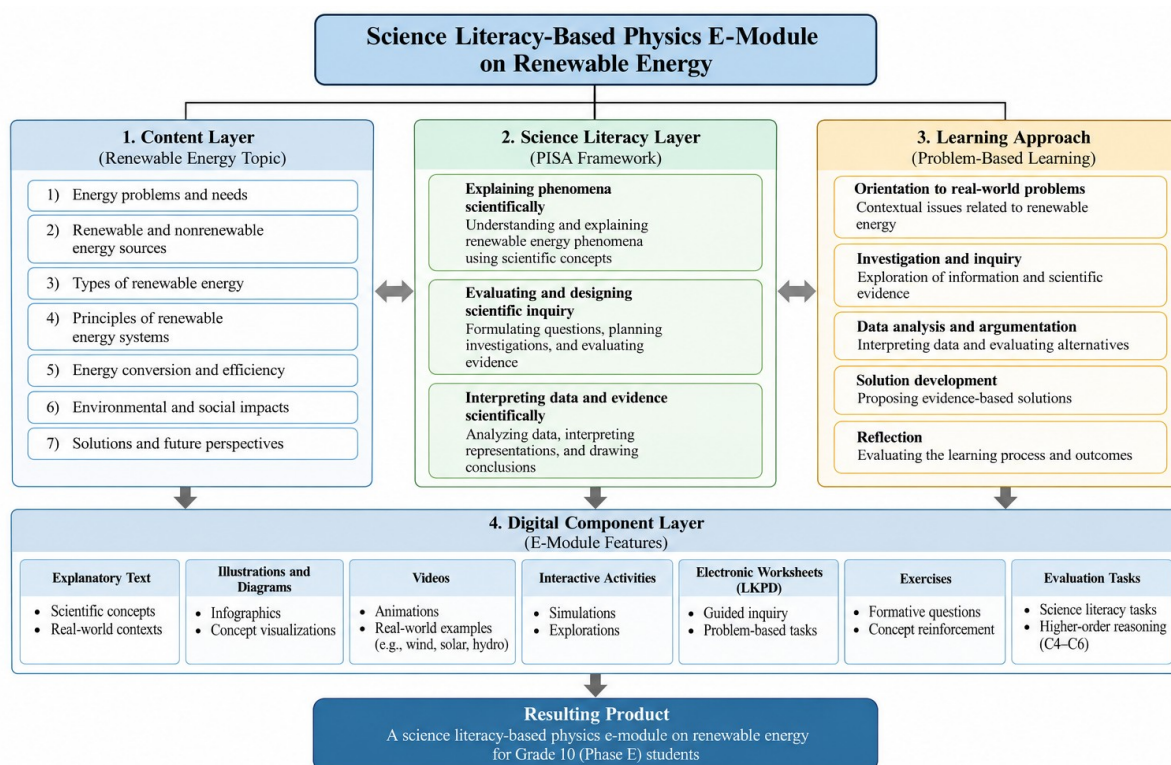


Figure 2. Architecture of the science literacy-based physics e-module

Product Characteristics

The Develop stage converted the design specifications into an e-module prototype for Grade 10 (Phase E) physics on renewable energy. The resulting product combines conceptual explanations with visual and

multimedia representations, interactive learning activities, electronic worksheets, exercises, and evaluation tasks. The components are arranged within a structured learning sequence so that students encounter scientific phenomena, investigate questions, interpret information, and formulate solutions in the context of renewable energy.

The resulting product can therefore be characterized as needs driven, science literacy oriented, problem centered, and multimedia-supported. Its structure goes beyond a simple digital reproduction of printed material because scientific reasoning activities are integrated into the learning sequence.

Representative pages of the developed e-module are shown in Figure 3. The examples illustrate the web based interface, renewable energy context, structured content presentation, and the organization of the first learning activity.



(a) Home page

(b) First activity

Figure 3. pages from the developed science literacy-based physics e-module

Expert Validation of the E-Module

The expert validation results are presented in Table 3. Three experts evaluated the developed e-module across four aspects: content, presentation, language, and graphics. The Aiken's V coefficients were 0.83 for content, 0.84 for presentation, 0.93 for language, and 0.87 for graphics, with an overall coefficient of 0.87. Based on the validity criterion adopted in this study, all aspect-level coefficients exceeded 0.80 and met the high validity criterion.

Table 3. Expert validation of the science literacy-based physics e-module.

Aspect	Aiken's V	Category
Content	0.83	Valid
Presentation	0.84	Valid
Language	0.93	Valid
Graphics	0.87	Valid
Average	0.87	Valid

The language aspect obtained the highest validity coefficient (0.93), followed by graphics (0.87), presentation (0.84), and content (0.83). Overall, the expert reviewers judged the developed product to meet the validity criteria across all four assessed aspects.

Practitioner Practicality Assessment

The practitioner practicality assessment was conducted with 10 physics teachers from senior high schools in South Sulawesi. As shown in Table 4, the overall practicality score was 84.58%, which was categorized as very practical. Content obtained the highest practicality score (86.94%), followed by graphics (85.00%), language (83.75%), and presentation (81.88%).

Table 4. Practitioner practicality assessment of the science literacy-based physics e-module.

Aspect	Score	Category
Content	86.94%	Very practical
Presentation	81.88%	Very practical
Language	83.75%	Very practical
Graphics	85.00%	Very practical

Average	84.58%	Very practical
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Discussion

The results demonstrate that the e-module was developed from a documented chain of needs rather than from the digital format alone. The preliminary study identified learner characteristics, technology readiness, curricular demands, and difficulties associated with renewable energy concepts, and these findings were converted into explicit design requirements [9]. An important design decision was to treat learning style information as contextual evidence rather than as a basis for assigning students to fixed categories. The visual (36%) and kinesthetic (32%) profiles therefore informed the provision of varied representations and opportunities for active engagement, while the predominantly moderate technology readiness (68%) supported the decision to use clear navigation and a structured sequence [9]. This approach keeps the learner analysis connected to design decisions without assuming that learning styles determine how students should be taught.

The architecture also demonstrates that science literacy was used as the organizing principle of the learning activities. The three selected competencies define what learners are expected to do with the physics content: explain renewable energy phenomena using scientific concepts, evaluate or design inquiry processes, and interpret data and evidence to reach conclusions [2]. This structure is important because science literacy involves the contextual use of scientific knowledge rather than the recall of isolated facts. The result is an instructional sequence in which conceptual explanations are followed or accompanied by opportunities to use information, evidence, and reasoning. The design is consistent with previous development studies showing the potential of science literacy oriented physics materials and digital learning resources to support higher order cognitive processes [3], [5], [7].

Problem-based learning strengthens this science-literacy orientation by providing a contextual pathway for using scientific knowledge. Renewable energy is particularly appropriate for problem-centered learning because questions of energy availability, conversion, efficiency, environmental consequences, and technology choice require students to connect physics concepts with real world situations. Within the developed architecture, a problem can lead students to identify relevant information, determine what evidence is needed, compare alternatives, and formulate a justified solution. In this arrangement, PBL does not replace science literacy; rather, it provides the context in which science literacy practices can be enacted. This complementary relationship is also consistent with previous work on problem-based and STEM oriented digital learning materials [8], [12], [14].

The multimedia design further supports the instructional architecture. CTML emphasizes the coordinated processing and integration of verbal and visual representations under the constraints of working memory [10]. Accordingly, multimedia elements in the present product were assigned instructional functions: explanatory text establishes conceptual grounding, illustrations and diagrams clarify processes and relationships, videos represent dynamic phenomena, and interactive activities provide opportunities to act on or interpret information. This is important because a visually attractive e-module is not necessarily pedagogically effective. Digital components need to be selected and organized in relation to the intended learning task, which is consistent with broader discussions of technology integration and instructional design [15], [16]. The resulting product therefore treats multimedia as part of the learning system rather than as decoration.

The expert validation results provide an additional indication that the design produced a coherent learning product. The overall Aiken's V coefficient of 0.87, with aspect-level values between 0.83 and 0.93, indicates that the content, presentation, language, and graphics met the high validity criterion used in the study. The relatively high language coefficient (0.93) suggests that the linguistic presentation was judged particularly appropriate, while the content (0.83) and presentation (0.84) coefficients indicate that the instructional and conceptual organization also satisfied the validation criteria. The graphics coefficient of 0.87 is consistent with the product's emphasis on visual representation and multimedia support. These values do not establish learning effectiveness, but they provide evidence that the developed material was considered appropriate by the expert reviewers before broader implementation.

The practicality findings complement the expert validation. The overall practicality score of 84.58% was categorized as very practical, with content receiving the highest score (86.94%) and presentation the lowest (81.88%). The difference across aspects is relatively small, suggesting generally consistent practitioner acceptance of the product while also identifying presentation as an area where further refinement may be useful. Because the practicality assessment was based on teacher responses, the finding is best interpreted as evidence of perceived usability and feasibility rather than as evidence of classroom effectiveness. Together, the validity and practicality findings strengthen the developmental contribution of the paper by showing that the design was not only theoretically specified but also positively evaluated by intended professional users.

The contribution of the present development lies in the explicit traceability between needs, design principles, and product features. Previous studies have reported interactive physics e-modules, science literacy-oriented modules, and renewable-energy learning resources [3]-[8], [12], [14]. The present product brings these strands together within a single needs-driven architecture in which science literacy determines the cognitive practices, PBL organizes the contextual learning pathway, and CTML guides the multimedia presentation. This traceability is visible in Tables 1 and 2 and in Figure 2, while Figure 3 provides concrete examples of the resulting interface and learning sequence. The product can therefore be positioned as more than a digital reproduction of printed material: its components are deliberately connected to scientific reasoning tasks and the contextual demands identified during the Define stage.

The scope of the findings should nevertheless be interpreted carefully. This paper establishes the development and initial quality of the product through expert and practitioner evaluation; it does not establish whether the e-module leads to higher critical-thinking performance than the instructional materials used in the control group. Controlled implementation and analysis of students' critical-thinking performance are therefore appropriate next stages of the broader development program. Future research should examine the product with larger and more diverse samples, multiple schools, and designs that can provide stronger evidence regarding learning outcomes. Within the present scope, the main implication is that a needs driven development process can translate learner and contextual evidence into a coherent science literacy-based digital learning architecture for renewable energy physics.

CONCLUSION

A science literacy-based physics e-module on renewable energy was developed for Grade 10 (Phase E) through a needs-driven process adapted from the Define, Design, and Develop stages of the 4D model. The Define stage established requirements from curriculum demands, learner characteristics, technology readiness, and renewable energy concept analysis. These requirements were translated during the Design stage into an architecture integrating science literacy competencies, problem-based learning, and multimedia principles informed by CTML. The Develop stage produced an e-module containing explanatory text, visual representations, multimedia, interactive activities, electronic worksheets, exercises, and evaluation. Expert validation yielded an average Aiken's V coefficient of 0.87, while practitioner assessment produced an overall practicality score of 84.58%, categorized as very practical. The results indicate that the developed product met the validity and practicality criteria used in the study. Its main contribution lies in the explicit alignment between documented needs and product features, with science literacy activities embedded as the organizing principle of the learning sequence.

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