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Development of a Local-Wisdom-Based Solar Oven E-Module to Enhance Students' Critical and Creative Thinking Skills in Renewable Energy Learning

Imelda Laelan Syafina[1,*], Ellianawati[1]

[1] Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Semarang 50229, Indonesia

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ABSTRACT

Renewable energy education requires contextual and future-ready learning strategies that connect scientific concepts with real-world sustainability challenges. This study aimed to develop and evaluate a local-wisdom-based solar oven e-module to enhance senior high school students' critical and creative thinking skills in renewable energy learning. The study employed a Research and Development design using the ADDIE model. Participants were Phase E students at a public senior high school in Central Java, Indonesia. Data were collected through expert validation sheets, student response questionnaires, and pretest–posttest instruments. The e-module achieved very high feasibility based on material and media expert validation. Statistical analysis revealed a significant improvement in students' critical and creative thinking skills, with the experimental group achieving a moderate N-Gain compared to the control group. These findings indicate that integrating renewable energy concepts with culturally contextualized digital learning materials can effectively support higher-order thinking development. The study contributes to the design of contextual digital instructional materials for sustainable science education.

1. Introduction

Many countries, including Indonesia, are currently facing the dual challenges of a global energy crisis and climate change [1]. The rapid growth of population and increasing energy demand have intensified dependence on fossil fuels, which are not only limited in availability but also contribute significantly to greenhouse gas emissions and global warming [2]. Consequently, the transition to renewable energy sources has become an essential strategy for achieving long-term environmental and energy sustainability [3].

As a tropical country with high solar irradiation, Indonesia has substantial potential for renewable energy development, particularly solar energy. The national solar energy potential is estimated to reach 207.8 GW; however, its utilization remains relatively low, as reported by the Kementerian

* *Corresponding author.*
E-mail address: imeldalaelan@students.unnes.ac.id

Energi dan Sumber Daya Mineral [4]. This gap between potential and actual utilization indicates the need for broader adoption of renewable energy technologies, especially in regions with limited access to conventional electricity infrastructure [1].

Semarang, as one of Indonesia's urban centers, offers significant opportunities for solar energy utilization across various sectors, including culinary practices rooted in local culture. One of the city's iconic traditional foods is *Lumpia*, which reflects strong cultural identity and local wisdom [5]. However, traditional cooking methods used in preparing local cuisine still rely heavily on fossil fuels, highlighting the need for environmentally friendly innovations [6]. A simple solar oven provides a practical alternative by utilizing solar energy for cooking purposes [7]. Despite its potential benefits, the adoption of solar oven technology remains limited due to low public awareness, insufficient understanding of its operational principles, and a lack of practical skills in its use [6].

Education plays a strategic role in addressing these challenges. Effective learning experiences are essential for equipping students with a meaningful understanding of renewable energy concepts and their real-world applications [8]. At the secondary school level, students have strong potential to act as agents of change within their communities [9]. However, renewable energy topics are often delivered theoretically, with limited opportunities for hands-on activities that enable students to apply concepts in authentic contexts [10]. As a result, students' critical and creative thinking skills related to sustainability issues remain underdeveloped [11].

Integrating local wisdom into learning materials can serve as an effective bridge between abstract scientific concepts and students' everyday experiences [12]. Linking solar oven technology with the preparation of *Lumpia* offers a contextual and culturally relevant learning approach that can enhance engagement and comprehension [13]. Nevertheless, educational modules that systematically integrate renewable energy concepts with local cultural practices are still scarce [14]. Moreover, limited attention has been given to the deliberate development of students' critical and creative thinking skills within renewable energy learning contexts [15].

Previous studies have demonstrated that solar ovens can reduce dependence on fossil fuels while producing adequately cooked food with lower environmental impact [16]. Research has also shown that differences in cooking methods influence food quality, including texture, color, and maturity levels [17]. Solar ovens are capable of reaching sufficient temperatures for cooking, although their performance depends on design characteristics and weather conditions [7]. Furthermore, solar cooking technologies have been identified as viable solutions for areas with limited access to electricity [18].

Despite these advantages, challenges persist in education and community adoption. A lack of knowledge and operational skills has been identified as a significant barrier to the widespread use of solar ovens [6]. In addition, integrating cultural elements into renewable energy education has been shown to increase acceptance and engagement with sustainable technologies [19].

Based on preliminary interviews with teachers at SMAN 15 Semarang, students have not yet achieved learning objectives related to identifying local energy potential and designing simple energy-producing prototypes. This limitation is attributed to restricted learning facilities, limited exposure to renewable energy technologies, and the absence of local wisdom integration in classroom instruction [20]. Notably, these learning objectives explicitly emphasize critical and creative thinking competencies, which align closely with the focus of this study.

Therefore, this research aims to develop a local wisdom–based e-module on simple solar ovens to enhance students' critical and creative thinking skills in renewable energy learning. By integrating project-based learning and culturally relevant contexts, this study is expected to provide meaningful learning experiences, strengthen conceptual understanding, and promote sustainability awareness among secondary school students [21].

1.2 Research Question

This study addresses the following research questions:

1. To what extent does the local-wisdom-based e-module improve students' critical and creative thinking skills in renewable energy learning?
2. How effective is the local wisdom-based e-module in enhancing students' critical thinking skills?
3. How effective is the local wisdom-based e-module in enhancing students' creative thinking skills?
4. How practical is the developed e-module when implemented in classroom learning?
5. What are the specifications of the developed local wisdom–based e-module on simple solar ovens?
6. What is the profile of students' critical and creative thinking skills after using the e-module?

1.3 Research Objectives

The general objective of this study is to develop and evaluate a local wisdom-based e-module on simple solar ovens to support renewable energy learning at the secondary school level.

1.3.1 Specific objectives

Specifically, this study aims to:

i. Evaluate the feasibility of a local wisdom-based e-module in improving students' critical and creative thinking skills.
ii. Examine the effectiveness of the e-module in enhancing students' critical thinking skills.
iii. Examine the effectiveness of the e-module in enhancing students' creative thinking skills.
iv. Assess the practicality of the developed e-module in classroom implementation.
v. Formulate the specifications of the local wisdom-based e-module on simple solar ovens.
vi. Analyze students' critical and creative thinking profiles after the implementation of the e-module.

2. Methodology

2.1 Research Design

This study employed a quantitative research approach using a Research and Development (R&D) design. The quantitative approach was selected to statistically examine changes in students' critical and creative thinking skills before and after the implementation of the developed e-module. R&D was chosen because the primary objective of this study was to design, develop, validate, and evaluate an instructional product in the form of a local wisdom-based renewable energy e-module, specifically focusing on a solar oven integrated with the local culinary context of local culinary context in Central Java [20,21].

The development procedure followed the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation.

2.2 Development Procedure

The research procedure was conducted according to the ADDIE model as follows:

1. *Analyze*
   The analysis stage involved identifying learning needs and existing problems through interviews with physics teachers and students. The analysis revealed that learning resources were limited to textbooks and internet sources, and no learning modules were used during instruction. Students also experienced difficulties in understanding renewable energy concepts. Additionally, local wisdom relevant to renewable energy learning was analyzed to support contextual learning.
2. *Design*
   At this stage, the structure and content of the e-module were designed. Learning materials focused on renewable energy topics, particularly solar energy, which was contextualized through the local wisdom of local culinary context in Central Java. A simple solar oven design was integrated into the-module to demonstrate practical application. The e-module structure included learning objectives, material explanations, illustrations, formative tests, and evaluation tasks. The e-module was designed using an online learning platform.
3. *Development*
   The e-module was developed by integrating learning materials, visual designs, interactive elements, and assessment instruments. Test items were constructed to measure students' critical and creative thinking skills and were reviewed through expert validation involving material experts, media experts, and physics teachers. Limited-scale trials and field trials were conducted to obtain feedback and ensure product feasibility.
4. *Implementation*
   The developed e-module was implemented in classroom learning activities. Students used the e-module during physics lessons on renewable energy, while the researcher conducted observations to examine students' engagement and interaction with the learning materials.
5. *Evaluation*
   Evaluation was conducted to determine the effectiveness of the e-module in improving students' critical and creative thinking skills. Data were collected using posttests and questionnaires, and the results were used to revise and refine the e-module.

The analysis stage focused on identifying instructional needs, learning objectives, and contextual relevance. Data were collected through interviews with physics teachers and students. The findings indicated that learning resources were predominantly limited to textbooks, with no use of instructional modules. Students also reported difficulties in understanding renewable energy concepts. Both teachers and students expressed the need for a structured learning module that includes conceptual explanations, examples, formative tests, and evaluation activities. These findings became the foundation for developing the e-module content and structure.

2.3 Participants

The participants of this study were Grade X students (Phase E) at SMAN 1 Bumiayu, Central Java, Indonesia. The population consisted of two Grade X science classes in the 2025/2026 academic year. A small-scale trial involved approximately 30–31 students, while the field trial involved 60-70 students from two classes.

2.4 Instruments and Data Collection

Data were collected using several instruments:

1. *Tests*
   Pretests and posttests were administered to measure students' critical and creative thinking skills before and after using the e-module. The test items were developed based on Bloom's taxonomy (C1–C6).
2. *Questionnaires*
   Questionnaires were used to collect data from material experts, media experts, physics teachers, and students. A Likert-scale questionnaire assessed the feasibility and quality of the e-module in terms of content, media design, language, and learning aspects.
3. *Observations and Documentation*
   Observations were conducted during the implementation stage to capture classroom interactions. Documentation included photographs and records of learning activities and validation sheets.

Data collection for students was conducted using digital forms, while expert and teacher validations were conducted using printed questionnaires.

2.5 Data Analysis

Data analysis in this study employed both qualitative and quantitative techniques. Qualitative data obtained from interviews, observations, and open-ended questionnaire responses were analyzed descriptively to support quantitative findings.

Quantitative data were analyzed to evaluate the effectiveness of the developed e-module in improving students' critical and creative thinking skills. The analysis procedures are described as follows.

2.5.1 Normality Test (Shapiro–Wilk)

Prior to inferential analysis, a Shapiro–Wilk normality test was conducted to determine whether pretest and posttest scores were normally distributed. This test was selected due to its suitability for small to moderate sample sizes.

The Shapiro–Wilk test statistic is formulated as:

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where:

$x_{(i)}$= ordered sample values

a_i = constants derived from the covariance matrix

$\bar{x}$ = sample mean

n = sample size

Decision criteria:

If $p > 0.05$, data are normally distributed

If $p \leq 0.05$, data are not normally distributed

2.5.2 Effectiveness test (Paired-Sample t-Test)

To determine whether there was a statistically significant difference between students' pretest and posttest scores, a paired-sample t-test was applied.
The t-test formula is expressed as:

$$t = \frac{\bar{d}}{\sqrt{\frac{\sum(d-\bar{d})^2}{n(n-1)}}}$$

where:
$\bar{d}$ mean difference between paired scores
d = difference between posttest and pretest scores
n = number of participants

Decision criteria:
If $p < 0.05$, there is a significant difference
If$p \geq 0.05$, there is no significant difference

2.5.3 Learning Improvement Analysis (N-Gain)

The magnitude of learning improvement was calculated using the normalized gain (N-Gain) score.

$$\langle g \rangle = \frac{\langle S_{post} \rangle - \langle S_{pre} \rangle}{100\% - \langle S_{pre} \rangle}$$

where:
S_{post} = posttest score
S_{pre} = pretest score
S_{max} = maximum possible score

Table 1
N-Gain interpretation criteria

N-gain Value	Improvement Category
$\langle \boldsymbol{g} \rangle > \mathbf{0.70}$	High
$\mathbf{0.30} < \langle \boldsymbol{g} \rangle \leq \mathbf{0.70}$	Medium
$\langle \boldsymbol{g} \rangle \leq \mathbf{0.30}$	Low

2.5.4 Instrument reliability test (Cronbach's Alpha)

Instrument reliability was assessed using Cronbach's Alpha to determine the internal consistency of the test items.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum {\sigma_i}^2}{{\sigma_t}^2}\right)$$

where:
k = number of items
${\sigma_i}^2$ = variance of each item
${\sigma_t}^2$= total variance

Table 2
Cronbach's Alpha interpretation

Alpha Value	Reliability Level
α ≥ 0.90	Excellent
0.80 ≤ α < 0.90	Good
0.70 ≤ α < 0.80	Acceptable
0.60 ≤ α < 0.70	Marginal
α < 0.60	Poor

2.5.5 Item difficulty index

The difficulty level of test items was analyzed using the following formula:

$$P = \frac{R}{N}$$

where:
P = difficulty index
R = number of students who answered correctly
N = total number of students

Table 3
Item difficulty interpretation

Difficulty Index (P)	Category
0.00 < P ≤ 0.30	Difficult
0.31 < P ≤ 0.70	Moderate
0.71 < P ≤ 1.00	Easy

2.5.6 Validity percentage analysis

The feasibility of the e-module based on expert and student questionnaires was calculated using the following formula:

$$V = \frac{\sum S}{S_{max}} \times 100\%$$

where:
$\sum S$ = total score obtained
S_{max} = maximum possible score

Table 4
Feasibility interpretation criteria

Percentage (%)	Category
81–100	Very Feasible
61–80	Feasible
41–60	Fair
21–40	Less Feasible
≤ 20	Not Feasible

3. Results and Discussion

3.1 Product Development Results

The developed product is a local wisdom–based solar oven e-module designed for Grade X senior high school students. The e-module contains renewable energy materials, learning activities, evaluation instruments, and contextual integration of local wisdom. The introductory section presents the development background, learning objectives, acknowledgments, and author contact information. The e-module is explicitly stated as a developing product subject to continuous refinement based on expert and user feedback.

The development process followed the ADDIE model, consisting of Analyze, Design, Development, Implementation, and Evaluation stages. This model was selected due to its systematic and comprehensive framework for producing valid, practical, and effective instructional products.

3.2 Expert Validation Results

3.2.1 Media expert validation

Media validation was conducted by five validators, consisting of two physics education lecturers and three experienced physics teachers. The evaluation covered visual design, readability, navigation, design consistency, and technical feasibility using a 5-point Likert scale.

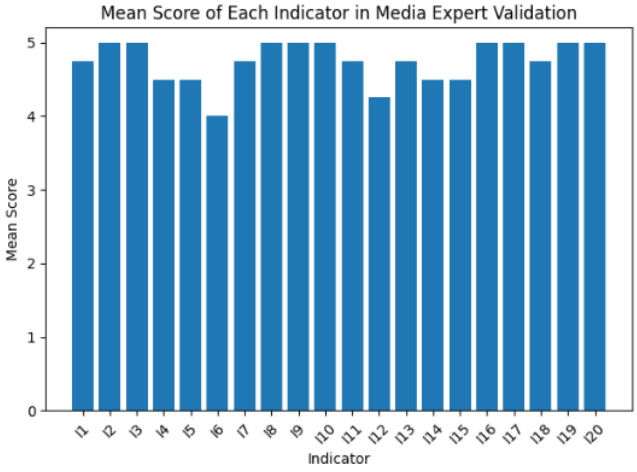

Fig. 1. Media expert validation results

Figure 1 presents the bar chart of mean scores for each indicator obtained from media expert validation. The results indicate that all indicators achieved mean scores ranging from 4.00 to 5.00, with a grand mean of 4.75. These findings suggest that the developed e-module demonstrates excellent quality in terms of visual design, readability, navigation, and technical feasibility. The high consistency of scores across indicators reflects strong agreement among validators regarding the overall suitability of the e-module for instructional use.

3.2.2 Material expert validation

Material validation involved two physics education lecturers and three physics teachers. The assessment focused on content accuracy, depth of material, alignment with the Merdeka Curriculum, logical sequencing, and contextual relevance.

Table 5
Material expert validation results

Indicator	Mean	Std. Dev
I1–I20	4.86	0.13

The grand mean score of 4.86 corresponds to a feasibility percentage of 97.25%, indicating that the e-module material is highly feasible. These results demonstrate strong epistemic alignment between learning objectives, content structure, and contextual integration of local wisdom.

3.3 Item Validity and Instrument Reliability
3.3.1 Item validity (Aiken's V)

Item validity was evaluated using Aiken's V index to measure inter-rater agreement.

Table 6
Aiken's V index results

Item	Aiken's V	Validity Category
1	0.955	Very valid
2	0.955	Very valid
3	0.965	Very valid
4	0.955	Very valid
5	0.955	Very valid
6	0.955	Very valid
7	0.970	Very valid
8	0.965	Very valid
9	0.960	Very valid
10	0.960	Very valid

All items achieved V ≥ 0.80, indicating excellent content validity.

3.3.2 Instrument Reliability

Reliability testing using Cronbach's Alpha yielded the following result:

Table 7
Reliability test results

Coefficient	Alpha	Number of Items	Category
Cronbach's Alpha	0.699	10	Moderately reliable

3.4 Effectiveness Based on Learning Outcomes
3.4.1 N-Gain analysis

Learning improvement was measured using normalized gain (N-Gain).

Table 8
N-Gain results

Class	N	Pretest Mean	Posttest Mean	N-Gain	Category
Experimental	31	61.6	82.0	0.51	Medium
Control	30	52.1	64.9	0.26	Low

3.4.2 Normality Test (Shapiro–Wilk)

Table 9
Normality test results

Test	Class	N	Sig.	Distribution
Pretest	Experimental	30	0.224	Normal
Pretest	Control	31	0.151	Normal
Posttest	Experimental	30	0.956	Normal
Posttest	Control	31	0.584	Normal

3.4.3 Paired Sample t-Test

Table 10
Paired Sample t-Test results

Class	Mean Difference	t	df	Sig. (2-tailed)	Result
Experimental	−12.80	−12.122	29	< 0.001	Significant
Control	−20.40	−11.835	30	< 0.001	Significant

3.5 Student Response Results

Table 11
Student response to the E-Module

Aspect	Mean Score	Percentage	Category
Media	4.20	84%	Very good
Display	4.25	85%	Very good
Learning	4.10	82%	Very good

3.6 Discussion

This study aimed to develop and evaluate the feasibility and effectiveness of a local wisdom–based solar oven e-module (EMOSKA) in enhancing senior high school students' critical and creative thinking skills. The discussion is structured around four main aspects: (1) product feasibility based on expert validation, (2) quality of assessment instruments, (3) effectiveness of the e-module in improving learning outcomes, and (4) students' responses toward the e-module.

3.6.1 Product feasibility from a digital learning perspective

The results of media and material expert validation indicate that the developed e-module achieved a very high level of feasibility. High validation scores reflect that the e-module fulfills fundamental principles of digital instructional design, including content accuracy, visual consistency, readability, and navigational clarity. Well-structured digital learning media are known to reduce extraneous cognitive load and allow learners to focus their cognitive resources on processing essential concepts, thereby supporting meaningful learning experiences [2,8,10].

From a content perspective, the high material validity score demonstrates strong epistemic alignment between the learning objectives, conceptual structure, and contextual examples embedded in the e-module. The integration of local wisdom does not merely function as an illustration, but serves as an authentic learning context that connects abstract physics concepts to students' everyday experiences. Such contextualization has been shown to strengthen conceptual understanding and increase learner engagement in science education [12-14].

3.6.2 Instrument quality and construct validity

The validity of the test items, as indicated by consistently high Aiken's V indices, confirms that the assessment instruments adequately represent the constructs of critical and creative thinking skills. The use of expert judgment–based validity analysis is widely recommended in development research to ensure content relevance, clarity, and construct representation, particularly when measuring higher-order thinking skills [11,15].

Furthermore, the reliability analysis using Cronbach's Alpha yielded a coefficient within the acceptable range for educational research. This finding indicates sufficient internal consistency, suggesting that the instrument can measure students' critical and creative thinking skills in a stable and consistent manner. In instructional development studies, such reliability levels are considered adequate for evaluating the effectiveness of learning interventions at the classroom scale [10,15].

3.6.3 Effectiveness of the E-Module in improving learning outcomes

The effectiveness of the e-module was examined through the analysis of pretest and posttest scores using N-Gain analysis, normality testing, and paired-sample t-tests. The use of N-Gain is particularly appropriate because it measures learning improvement proportionally relative to students' initial knowledge levels, providing a more meaningful interpretation of learning gains than raw score differences alone [20].

The experimental class achieved a moderate N-Gain, while the control class showed a low N-Gain, indicating that the e-module contributed more substantially to learning improvement than conventional instruction. This result is consistent with previous studies reporting that project-based learning environments promote deeper cognitive engagement and higher learning gains compared to traditional teacher-centered approaches [9,15,20].

Prior to inferential analysis, data normality was assessed using the Shapiro–Wilk test, which is considered more statistically powerful for small to moderate sample sizes. The confirmation of normal data distribution justified the use of parametric statistical testing, specifically the paired-sample t-test [20]. The paired-sample t-test results revealed statistically significant differences between pretest and posttest scores in both experimental and control groups. However, when interpreted alongside the N-Gain results, it is evident that the experimental group experienced a qualitatively superior learning improvement. This finding suggests that the observed effectiveness is attributable not merely to score increases, but to the instructional quality and learning experience facilitated by the e-module [9,21].

3.6.4 Role of local wisdom in Higher-Order Thinking Development

The incorporation of local wisdom within the e-module plays a critical role in fostering students' critical and creative thinking skills. Contextual learning activities encourage students to analyze real-world problems, evaluate alternative solutions, and design creative responses based on their environmental and cultural surroundings. These learning conditions are aligned with constructivist learning theories, which emphasize active knowledge construction through meaningful and context-rich experiences [12,19].

By engaging students with locally relevant phenomena, such as the integration of solar oven technology with traditional culinary practices, the e-module supports deeper conceptual processing and enhances knowledge transfer to new situations. Previous studies have shown that culturally

responsive learning environments increase student motivation, conceptual understanding, and acceptance of sustainable technologies [13,19].

3.6.5 Students' responses and affective learning outcomes

Students' responses toward the e-module were overwhelmingly positive across all evaluated aspects, including media quality, presentation, and learning experience. Positive affective responses are important indicators of instructional success, as motivation and engagement strongly influence students' willingness to participate actively in learning activities and persist in solving complex problems [9,10].

High levels of engagement contribute to sustained cognitive effort, which in turn enhances learning outcomes, particularly in project-based and inquiry-oriented learning environments. Therefore, the positive student responses observed in this study provide complementary evidence supporting the quantitative findings related to learning improvement [15,20].

3.6.6 Theoretical synthesis

Overall, the findings suggest that integrating local cultural contexts into renewable energy learning can enhance students' engagement and support higher-order thinking development. However, while the study indicates positive cognitive learning outcomes, environmental attitudes and sustainability values were not directly measured. Therefore, conclusions regarding long-term behavioral or attitudinal impacts should be interpreted cautiously and require further empirical investigation [9,12,15,21].

The development of critical and creative thinking skills in this study aligns with key competencies emphasized in 21st-century learning frameworks and the Merdeka Curriculum, particularly higher-order thinking skills (HOTS), problem-solving, and contextual learning. However, this alignment was inferred from cognitive performance indicators measured through test instruments rather than from a comprehensive curriculum implementation analysis. Future studies should incorporate explicit curriculum mapping and competency-based performance indicators to strengthen claims of curricular alignment [12,21].

4. Conclusion

This study developed and evaluated a local-wisdom-based solar oven e-module for renewable energy learning at the senior high school level. Based on expert validation results, the e-module achieved a very high feasibility level in terms of content accuracy, instructional design, media quality, and curriculum alignment. The assessment instruments demonstrated strong content validity and acceptable reliability, indicating that they were appropriate for measuring students' critical and creative thinking skills.

Empirical findings from the implementation stage indicate that the use of the e-module contributed to a statistically significant improvement in students' learning outcomes. The experimental class achieved a moderate N-Gain, while the control class showed a lower improvement level. These findings suggest that integrating contextual renewable energy learning with local wisdom and digital instructional media can support the development of higher-order thinking skills, particularly critical and creative thinking.

However, several limitations should be acknowledged. First, the study was conducted within a limited geographic context and involved students from a single school, which may restrict the

generalizability of the findings. Second, the implementation period was relatively short, preventing the examination of long-term learning retention and sustained impact on thinking skills. Third, the study primarily focused on cognitive outcomes and did not quantitatively measure environmental attitudes or sustainability behaviors.

Future research is recommended to test the e-module in different regions, educational levels, and subject areas to examine its broader applicability. Longitudinal studies are also needed to investigate long-term impacts on students' critical and creative thinking skills as well as their sustainability awareness. In addition, further studies may explore comparative designs or quasi-experimental approaches with larger samples to strengthen the robustness of empirical evidence.

Overall, the findings indicate that a systematically developed local-wisdom-based digital e-module can serve as an effective instructional innovation in renewable energy education, particularly in fostering students' higher-order thinking skills within a contextual learning framework.

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