Development and Validation of the EcoThermal Literacy Assessment: An Instrument for Environmental Literacy in Thermodynamics Learning

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Abstract *- Global environmental issues are becoming increasingly alarming and require serious attention. Enhancing students' environmental literacy is a strategic step in fostering awareness and sustainable actions. Thermodynamics in physics has the potential to be linked to environmental issues, but no specific assessment instrument is available to evaluate students' environmental literacy. This study aims to ensure the validity and reliability of the EcoThermal Literacy Assessment as an evaluation instrument for environmental literacy in learning thermodynamics. This instrument comprises four main dimensions: knowledge (physical and ecological systems, environmental issues, problem-solving solutions, action strategies), competence (identification, analysis, evaluation, argumentation of environmental issues), attitude (sensitivity, concern, environmental motivation), and behavior (environmental actions, problem prevention, resource management). The study employs the 4-D R&D model. Content validity is tested using Aiken's V index, while empirical validity is examined through Pearson correlation. Reliability is measured using Cronbach's Alpha, while discrimination power and difficulty levels are analyzed using SPSS 27. Most items exhibit high validity and good reliability (α = 0.802–0.936). The majority have moderate to good discrimination power, but some in the knowledge dimension have low discrimination power and require revision. The difficulty level is predominantly moderate to easy. This study focuses on evaluating the instrument's validity and reliability, without testing its impact on student learning outcomes. The findings can serve as a reference for assessment development and further research on the practicality of the instrument in physics learning integrated with environmental issues.*

Keywords*: EcoThermal Literacy Assessment; Environmental Literacy; Thermodynamics*

INTRODUCTION

Global environmental issues have reached an alarming level and require serious attention. According to the OECD Environmental Outlook to 2050: The Consequences of Inaction (2012), there are four major environmental problems that need to be addressed immediately: climate change, biodiversity loss, water scarcity, and air pollution. The 2022 Indonesia Environmental Status Report highlights the concerning state of the environment, with an annual deforestation rate of 1.1 million hectares and air quality in major cities exceeding safety thresholds (Kementerian Lingkungan Hidup dan Kehutanan, 2022). Addressing these issues, education plays a crucial role in raising public awareness and understanding, one of which is through environmental literacy.

Improving environmental literacy is a strategic step in fostering awareness and concrete actions to preserve the environment (Grace Modupe Bada et al., 2024). Strong environmental literacy enables individuals to make informed decisions and take real actions for environmental sustainability, both individually and collectively (McBeth & Volk, 2009). Environmental literacy consists of four key dimensions: knowledge, attitude, competence, and responsible behavior toward the environment. Knowledge encompasses ecological, social, and environmental issues, while attitude

reflects individual concern. Competence represents the ability to identify and solve environmental problems, and responsible behavior is demonstrated through tangible actions to protect the environment (Hollweg et al., 2011).

The level of environmental literacy among students in Indonesia still needs improvement (Ahmadi, 2022). Studies in several regions of Indonesia indicate that students' understanding of environmental issues tends to focus on knowledge, while their attitudes and real behaviors toward environmental conservation have not been optimally developed (Dharma & Arriah, 2024; Hanafi et al., 2021; Nasution, 2016; Santiani, Rusilowati, et al., 2023; Wardani, 2017). A positive attitude toward environmental conservation does not always translate into concrete actions in daily life (Safitri et al., 2024). One contributing factor to the low level of environmental literacy is the lack of integration between learning materials and local environmental issues, as well as the absence of an evaluation instrument that can comprehensively assess conceptual understanding, analytical skills, and students' attitudes and behavioral tendencies (Dharma & Arriah, 2024; Jarwopuspito et al., 2023). One approach to improving students' environmental literacy is through physics learning, particularly in thermodynamics.

Integrating thermodynamics into physics learning allows students to understand the relationship between scientific principles and environmental issues. Integrating environmental issues into physics education has been proven to enhance students' understanding of environmental phenomena, especially when combined with experiment-based and project-based learning (Lestari, et al., 2024a; Lestari,et al., 2024b; Santiani & Annovasho, 2023; Santiani, et al., 2023). A transdisciplinary approach in physics education such as applying the Waste-to-Energy (WTE) concept in thermodynamics and exploring renewable energy development (Yustiana et al., 2024), as well as integrating Education for Sustainable Development (ESD) (Jauhariyah et al., 2021) has also been developed to promote deeper conceptual understanding while fostering environmental awareness.

Thermodynamics learning is inherently linked to environmental issues, yet many educators have not explicitly integrated these aspects into their teaching. Various environment-based learning models have been developed, but the evaluation instruments used remain general and do not specifically assess how students connect thermodynamics concepts with sustainability and environmental impact (Rianty et al., 2024). Most available assessments focus on higher-order thinking skills (HOTS) (Barokah et al., 2021) or scientific argumentation (Deke et al., 2022) without considering environmental integration in the thermodynamics context. This condition highlights the need for a more targeted evaluation instrument to assess the connection between thermodynamics and environmental sustainability.

Developing an environmental literacy assessment within thermodynamics learning has become an urgent necessity. This study develops the EcoThermal Literacy Assessment, an instrument designed to evaluate the relationship between thermodynamics concepts and environmental sustainability. This assessment aims to measure students' understanding of energy efficiency, entropy, heat transfer, thermodynamic laws, renewable energy, and local environmental issues such as peatlands, the greenhouse effect, and global warming. The EcoThermal Literacy Assessment is expected not only to

strengthen students' physics comprehension but also to enhance their awareness and skills in applying sustainability principles, making physics learning more relevant to current environmental challenges. This study focuses on validity and reliability testing of the instrument, with results serving as a foundation for further assessment development in environmentally integrated physics education.

RESEARCH METHODS

This study employs the Research and Development (R&D) method (Borg & Gall, 1989) using the 4-D (Four-D) development model, which consists of define, design, develop, and disseminate stages (Thiagarajan et al., 1974). The first stage define, aims to analyze needs and establish the foundation for developing the EcoThermal Literacy Assessment. This involves identifying problems, analyzing student characteristics, and mapping thermodynamics concepts to align with environmental literacy.

The second stage design, involves developing the assessment instrument based on needs analysis and objective specifications. The assessment framework is presented in Tables 1 and 2. The instrument consists of multiple-choice tests, essay questions, and attitude and behavior questionnaires using a Likert scale (1-5) administered via Google Forms for easier data collection.

Table 1. EcoThermal Literacy Assessment Framework: Knowledge and Competence Dimensions

Dimension	Indicator	Material	Cognitive Level
Knowledge	Physical and ecological systems	First Law of Thermodynamics	C2 Understanding
	Environmental issues	Second Law of Thermodynamics	C2 Understanding
	Various solutions to environmental issues	Renewable Energy in the context of thermodynamics	C3 Application
	Community participation and action strategies	Climate change mitigation efforts	C3 Application
Competence	Identifying environmental issues	Heat Engine Efficiency and its impact	C4 Analysis
	Analyzing environmental issues	Effect of Temperature on Gas Volume in Industry	C4 Analysis
	Evaluating and making personal judgments	Energy waste reduction strategies	C5 Evaluation
	Using evidence and knowledge to support positions on environmental issues	Impact of global warming on ecosystems	C5 Evaluation

Table 2. EcoThermal Literacy Assessment Framework: Attitude and Behavior Dimensions

Dimension	Indicator	Material	Cognitive Level
Attitude	Sensitivity to environmental issues	Climate change and its impacts	A1 Receiving
	Concern for the environment	Responsible energy use	A2 Responding
	Motivation and intention to act	Participation in environm	A3 Valuing

Dimension	Indicator	Material	Cognitive Level
		ental activities	
Behavior	Active involvement in solving environmental problems	Participation in reforestation activities	A4 Organization
	Prevention of new environmental problems	Efficient energy use	A5 karacterization
	Resource management (eco-management)	Waste reduction and energy recycling	

The third stage development includes expert and empirical validation. Expert validation is tested using Aiken's V index with five expert validators. The critical V-value for five raters at a 5% significance level is 0.87. Each instrument item is deemed valid if V-calculated > 0.87 (Aiken, 1985). Items are evaluated based on content, construct, and language validity. Empirical validation is conducted after the expert validation process. The validated EcoThermal Literacy Assessment is then tested to assess its empirical validity and reliability. The instrument trial was conducted at SMAN 1 Palangka Raya with 38 twelfth-grade students (14 males and 24 females). Data were analyzed using SPSS 27 to measure validity, reliability, item discrimination, and difficulty level.

The results of this limited trial were used to revise the instrument for better suitability in learning. Validity testing was conducted using Pearson correlation (Pearson, 1920), and reliability testing was performed using Cronbach's Alpha (Cronbach, 1951). Item discrimination was interpreted based on index values: very good ($0.70 < DP \leq 1.00$), good ($0.40 < DP \leq 0.70$), fair ($0.20 < DP \leq 0.40$), poor ($0.00 < DP \leq 0.20$), and very poor ($DP \leq 0.00$) (Lestari & Yudhanegara, 2015). The difficulty level was determined based on the proportion of correct responses, categorized as: too difficult ($P = 0.00$), difficult ($0.00 < P \leq 0.30$), moderate ($0.30 < P \leq 0.70$), easy ($0.70 < P < 1.00$), and too easy ($P = 1.00$) (Lestari & Yudhanegara, 2015)

The final stage disseminate, aims to distribute the revised and validated instrument for use in thermodynamics learning to assess students' environmental literacy. Dissemination is conducted through scientific article publication, providing a reference for further research, particularly in studies evaluating the implementation and practicality of the instrument in learning environments.

RESULTS AND DISCUSSION

The implementation of the define stage produced findings from the pre-observation analysis using questions and a questionnaire adapted from a previous study (Karuni, 2020), which was given to 39 twelfth-grade students at SMAN 1 Palangka Raya, showing that students' environmental literacy was still relatively low. This condition aligns with research in Indonesia, which indicates that students' cognitive aspects of environmental literacy remain weak (Rokhmah et al., 2021; Santoso et al., 2021). Similar challenges were also found globally in a study by Panchal & Moschandreas (2015) in the United States, which revealed that many respondents had a limited understanding of sustainability, including environmental issues, resource management, and sustainable actions in daily life. Direct interviews with teachers also revealed the need for an assessment tool that not only measures students' understanding of thermodynamics concepts but also connects them to relevant environmental issues, including peatland

environments. The importance of environmental education in increasing students' awareness and literacy has been highlighted by Yadav et al. (2021), who emphasized that integrating environmental issues into the curriculum can help build awareness of sustainability and encourage concrete actions toward environmental problems.

As an initial step to enhance students' awareness, brochures were prepared as an informative medium before the assessment to provide an understanding of environmental issues, including peatland ecosystems. Additionally, the concept mapping results based on CP and ATP showed that certain parts of the thermodynamics material could be contextualized with environmental phenomena, including peatland environments, which were visualized in a concept map as the basis for developing the evaluation instrument.

The second stage, design, focused on developing the assessment based on the environmental literacy model by Hollweg et al. (2011), which was designed to encompass three main dimensions: knowledge, competence, and attitudes and behavior. The knowledge dimension was measured using multiple-choice tests consisting of 25 questions. Multiple-choice tests were chosen to assess the knowledge dimension because they can cover a broad range of material, produce reliable scores, and are efficient in both implementation and evaluation. Additionally, if well-designed, these instruments can measure understanding, critical thinking, and problem-solving (Haladyna, 2022). The competence dimension was measured through 13 essay questions designed to develop higher-order thinking skills. Essay questions allow students to analyze, evaluate, and develop solutions more deeply than multiple-choice questions and test their argumentation and reasoning skills (Rani & Badusha, 2023).

The attitudes and behavior dimension was measured using a questionnaire consisting of 19 statements to assess attitudes and 9 statements to assess students' behavior. The questionnaire was chosen because it can objectively and consistently measure affective aspects and reflect students' attitudes and behavioral tendencies toward the environment (Kurniawan et al., 2022). This assessment does not only evaluate the cognitive aspect to measure students' understanding of thermodynamics concepts and environmental issues but also the affective aspect to assess their awareness and commitment to applying sustainability values in daily life. Previous studies have shown that while students' environmental literacy levels are relatively good, their environmental behavior remains low, so an assessment measuring both aspects is necessary to obtain a more comprehensive picture (Dissanayake, 2024).

The third stage, develop, includes expert validation and empirical validation. Expert validation is a crucial stage in the development of the EcoThermal Literacy Assessment to ensure that each test item aligns with the indicators being measured. The minimum validity threshold depends on the number of raters and the rating scale category (Aiken, 1985). Based on the Aiken's V critical value table, for 5 raters at a 5% significance level, the V table value used is 0.87.

Expert validation results for the EcoThermal Literacy Assessment multiple-choice test showed that all test items had validity values above 0.90, ranging from 0.93 to 0.99. All test items were declared valid, as shown in Figure 1. This indicates that the EcoThermal Literacy Assessment has met good content validity criteria and

can thus be used to measure students' knowledge dimension of environmental literacy in the context of thermodynamics.

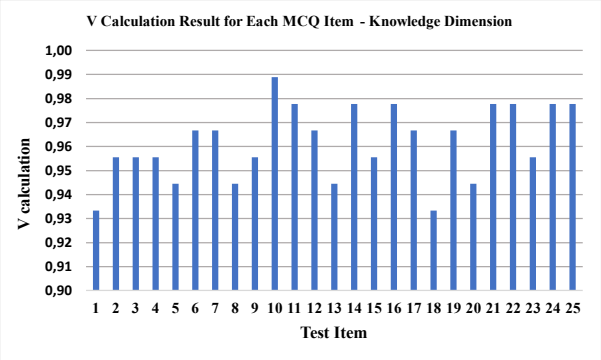

Figure 1. Expert Validation Results for the EcoThermal Literacy Assessment Multiple-Choice Test Knowledge Dimension

The essay test instrument used to measure students' competence also demonstrated high validity, with V values ranging from 0.94 to 0.98 (Figure 2). All test items were declared valid, indicating that these essay questions are capable of measuring students' critical and analytical thinking skills regarding environmental issues based on physics concepts.

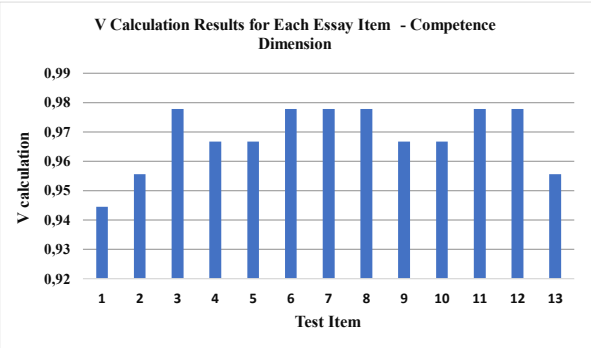

Figure 2. Expert Validity Results of the EcoThermal Literacy Assessment for Essay Tests in the Competence Dimension

The EcoThermal Literacy Assessment for the questionnaire used to measure students' attitude and behavior dimensions has also undergone expert validity testing. In the attitude dimension, the V value ranges from 0.92 to 0.98 (Figure 3), while in the behavior dimension, the V value ranges from 0.93 to 0.98 (Figure 4). All questionnaire items were declared valid, indicating that this EcoThermal Literacy Assessment can measure students' attitudes and behaviors toward environmental issues accurately and consistently.

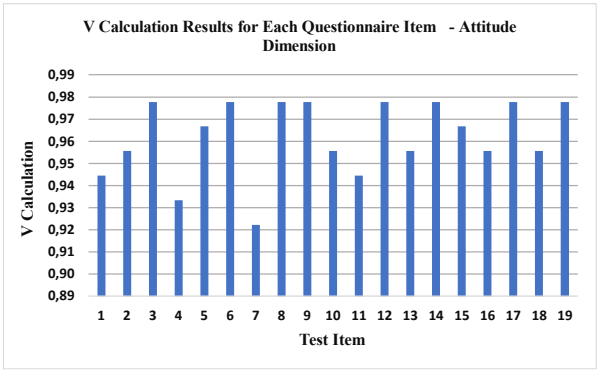

Figure 3. Expert Validation Results of the EcoThermal Literacy Assessment for Questionnaire in the Attitude Dimension

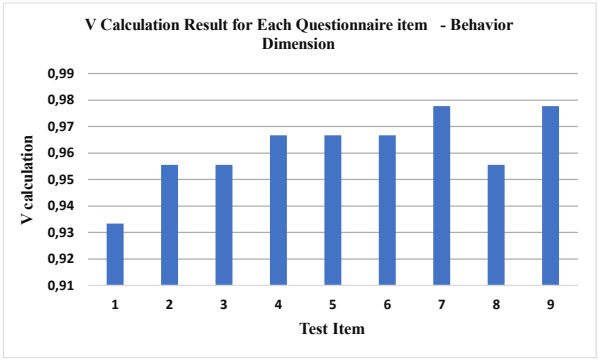

Figure 4. Expert Validation Results of the EcoThermal Literacy Assessment for Questionnaire in the Behavior Dimension

Expert validation results indicate that all instruments have met the criteria for content validity with V calculated > 0.87, thus declared valid. Farwati (2018) found that Aiken's V index can be effectively used to assess the validity of environment-based assessment instruments, which aligns with the findings of this study. After revisions and expert validation, the instrument was then tested on students through empirical validation to ensure its validity and reliability in measuring students' environmental literacy in thermodynamics.

Empirical validation was conducted through instrument trials on 32 twelfth-grade students at SMAN 1 Palangka Raya who had studied thermodynamics. Before the trial, students were provided with supplementary materials in the form of environmental brochures distributed two days earlier to reinforce their understanding of environmental issues, including peatland environments. The validity results using SPSS for the EcoThermal Literacy Assessment in the knowledge dimension are presented in Figure 5.

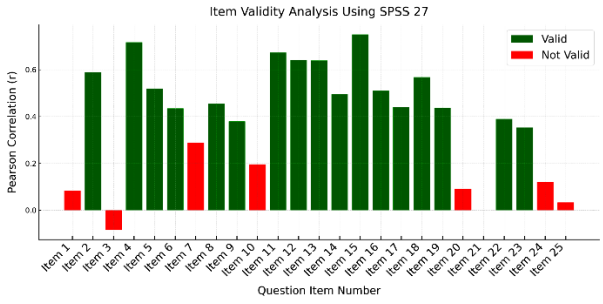

Figure 5. Item Validity Analysis Results of the Multiple-Choice Test for the Knowledge Dimension in the Field Trial Using SPSS 27

Figure 5 presents the item validity analysis of the multiple-choice test for assessing students' environmental literacy in the knowledge dimension. The analysis was conducted using Pearson's product-moment correlation with N = 32, comparing the calculated r-value with the critical r-table value (0.3494) at a 5% (0.05) significance level. An item is considered valid if the calculated r-value exceeds the r-table value. The analysis results show that 13 out of 25 items are valid, with calculated r-values ranging from -0.084 to 0.750. The item with the highest r-value (0.750) indicates a strong correlation with the total score, while several invalid items need revision. These findings align with the study by Farwati (2018), which found that some items in environmental literacy assessments were invalid and needed modification to better match the measured indicators, eliminate ambiguity, and adjust difficulty levels. The study by Szczytko et al. (2019) further emphasized that questions relevant to real-world environmental contexts tend to have higher validity compared to purely theoretical ones.

The validity analysis results for the competency dimension in the EcoThermal Literacy Assessment using essay questions are presented in Figure 6.

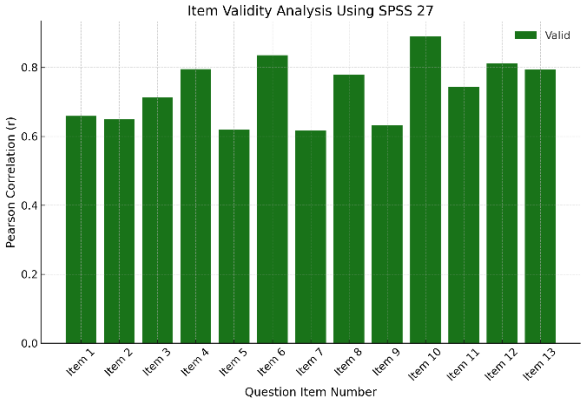

Figure 6. Item Validity Analysis Results of the Essay Test for the Competency Dimension in the Field Trial Using SPSS 27

The calculated r-values range from 0.617 to 0.890, indicating that each item has a strong correlation with the total score. All items are declared valid, meaning that the EcoThermal Literacy Assessment meets the validity criteria and is suitable for measuring students' environmental literacy competency in the form of essay questions. A similar study was conducted by del Socorro, Valdez-Tribolet, and Adán Guillermo (2024), who also used Pearson's Product Moment test to assess the validity of a sustainability competency assessment instrument for university students. Their results showed r-values ranging from 0.535 to 0.606, indicating moderately strong validity. A comparison with this study shows that the obtained r-value range is higher (0.617 – 0.890), indicating differences in correlation strength, which may be

influenced by factors such as research context and respondent characteristics.

The validity analysis results for the attitude dimension in the EcoThermal Literacy Assessment using a questionnaire are presented in Figure 7.

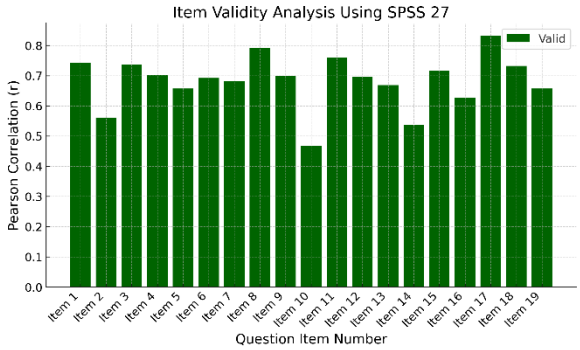

Figure 7. Item Validity Analysis Results of the Questionnaire for the Attitude Dimension in the Field Trial Using SPSS 27

Based on the calculation results, the r-values range from 0.467 to 0.832, with all items having a significant value below 0.05. This indicates that all statements in the questionnaire have a significant correlation with the total score, thus they can be declared valid.

The analysis results in Figure 8 show that all items have an r-value greater than the r-table, ranging from 0.618 to 0.870, thus all items are declared valid. The validity of the EcoThermal Literacy Assessment indicates that each item in the questionnaire is able to consistently measure students' attitudes and behaviors. Unlike multiple-choice and essay questions, the EcoThermal Literacy Assessment in the form of a questionnaire to measure attitudes and behaviors does not solely rely on the accuracy of responses but also on the consistency of students' responses to a given statement (Mujib et al., 2023).

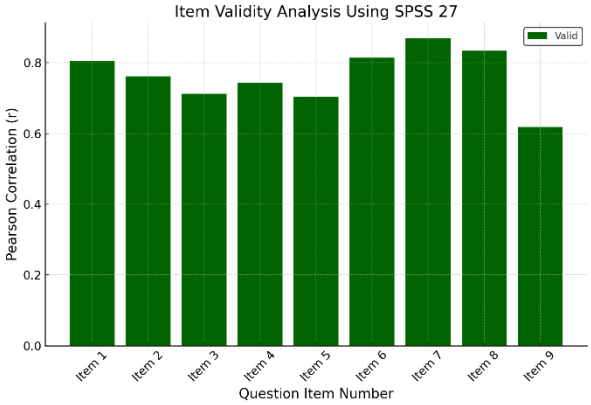

Figure 8. Item Validity Analysis Results of the Questionnaire for the Behavior Dimension in the Field Trial Using SPSS 27

In addition to the validity test, the EcoThermal Literacy Assessment was also analyzed based on reliability, discrimination index, and difficulty level to ensure the quality of the test items used. The reliability test aims to assess the consistency of students' answers, while the discrimination index measures the ability of the test items to distinguish students with different levels of understanding. Meanwhile, the difficulty level is used to determine the extent to which test items can be understood by respondents. The results of the reliability, discrimination index, and difficulty level analysis in this study are presented in Table 3.

Table 3. Reliability, Discriminatory Power, and Difficulty Level Analysis of Test Items Using SPSS 27

Dimension	Reliability	Discriminatory Power					Difficulty Level		
		vg	g	f	p	vp	d	m	e
Knowledge	0,802	-	37,5%	29,17%	4,17%	16,67%	-	56%	44%
Competence	0,923	46,15%	53,85%	-	-	-	-	100%	-
Attitude	0,936	26,32%	68,42%	5,26%	-	-	-	-	-
Behavior	0,910	50%	50%	-	-	-	-	-	-

*vg= very good; g= good; f= fair; p= poor; vp = very poor
*d= difficult; m= moderate; e= easy

All dimensions have high reliability coefficients, ranging from 0.802 to 0.936, indicating good internal consistency. A reliability coefficient above 0.80 indicates good reliability, while a value above 0.90 falls into the very good category (Budiastuti & Bandur, 2018). This value is higher compared to a previous study by Mujib et al. (2023), which obtained reliability between 0.66 and 0.78. This difference may be due to variations in the number of test items, the validation methods used, or the characteristics of the respondents.

The discrimination index analysis results show that most test items fall into the good to very good categories. In the knowledge dimension, 37.5% of the items fall into the good category, 29.17% are sufficient, 4.17% are poor, and 16.67% are very poor. In the competency dimension, 46.15% of the items have a very good discrimination index, while 53.85% are good. For the attitude dimension, 26.32% of the items have a very good discrimination index, 68.42% are good, and 5.26% are sufficient. Meanwhile, in the behavior dimension, 50% of the items have a very good discrimination index, and 50% are good.

The difficulty level analysis results indicate that most test items fall into the moderate category, which represents an ideal distribution in a test. In the knowledge dimension, 56% of the items are in the moderate category, while 44% are in the easy category. In the competency dimension, 100% of the items fall into the moderate category, indicating that the difficulty level of this instrument aligns with students' abilities. The questionnaire for measuring attitude and behavior does not require difficulty level analysis since it does not have right or wrong answers but rather measures students' tendencies and response intensities to a given statement (Budiastuti & Bandur, 2018).

These findings align with Szczytko et al. (2019), who stated that an environmental literacy assessment instrument must balance difficulty level and discrimination power to effectively measure cognitive, affective, and behavioral aspects. The study by Aswita et al. (2022) also showed that a valid instrument must have good discrimination power to differentiate students with varying levels of understanding and a range of difficulty levels to accommodate students' different abilities.

The final stage, disseminate, was carried out by publishing the development results of the EcoThermal Literacy Assessment in a scientific journal to support the development of environmental literacy assessment instruments and physics education. Publication in a scientific journal is sufficient to fulfill the dissemination stage, as it allows research findings to be distributed and utilized in the development of assessment instruments (Thiagarajan et al., 1974). This publication also ensures that the instrument, which has undergone validity and reliability testing, can be widely used in education (Ayu et al., 2018; Hardiansyah et al., 2022).

CONCLUSION

The research results indicate that the EcoThermal Literacy Assessment has high validity and reliability in measuring environmental literacy within thermodynamics material. In the knowledge dimension, most test items are valid, covering indicators such as physical and ecological systems, environmental issues, problem-solving solutions, and action strategies. The majority of items exhibit sufficient to good discrimination power, with difficulty levels ranging from moderate to easy. However, some items have low

discrimination power and need improvement to achieve a more ideal difficulty level and more accurate measurement. The competency dimension, which includes identification, analysis, evaluation, and argumentation of environmental issues, has good to very good discrimination power, with most items at a moderate difficulty level. The attitude dimension, measured through indicators of sensitivity, concern, and environmental motivation, as well as the behavior dimension, which includes environmental action, problem prevention, and resource management, has good to very good discrimination power and high reliability, with Cronbach's Alpha values ranging from 0.802 to 0.936, ensuring consistency in measuring students' tendencies toward environmental issues. These findings suggest that the EcoThermal Literacy Assessment can be used as a valid and reliable evaluation tool for measuring students' environmental literacy while supporting physics learning that is more contextual and relevant to environmental issues. Future research may examine the implementation of this assessment in classroom learning to evaluate its practicality.

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