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STUDENTS' SYSTEMS THINKING IN SUSTAINABILITY-ORIENTED SCIENCE EDUCATION: EVIDENCE FROM RENEWABLE ENERGY LEARNING IN AN ISLAMIC UNIVERSITY

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ABSTRACT
Sustainability education requires students to understand environmental challenges as interconnected systems involving scientific, technological, and environmental processes. This perspective is particularly relevant to Islamic higher education, where scientific learning is expected to foster environmental responsibility and stewardship (*khalifah fil ardh*). However, empirical evidence remains limited regarding how Biology Education students understand the interrelationships within renewable energy systems through authentic biomass-based sustainability contexts. This study examines students' systems thinking abilities in understanding renewable energy from rice husk biomass and evaluates the measurement characteristics of the assessment instrument as a preliminary basis for sustainability-oriented science education. A quantitative descriptive approach was employed involving 19 Biology Education students at Universitas Muhammadiyah Sukabumi. Data were collected using a 10-item essay instrument representing six dimensions of systems thinking and analyzed using the Rasch measurement model. The findings indicate that seven items demonstrated acceptable fit across the specified Rasch criteria, while three items required further attention. Although most students were categorized as having high ability, relatively low person reliability (0.59) and person separation (1.19) limited the instrument's ability to distinguish individual performance consistently. Item difficulty analysis further revealed that students experienced greater challenges in integrating scientific, technological, and sustainability considerations, particularly when developing sustainable energy solutions. These findings provide preliminary empirical insights into the relationship between systems thinking and renewable energy learning. The study contributes to sustainability-oriented science education by highlighting the importance of developing students' capacity to connect scientific understanding with environmental responsibility. Within Islamic higher education, this perspective reinforces the educational relevance of environmental stewardship (*khalifah fil ardh*) while providing an empirical foundation for future instructional development, including the potential use of technology-supported learning approaches.

Keywords: Systems thinking, Sustainability education, Science education, Renewable energy, Rasch model, Islamic higher education

INTRODUCTION

Sustainability has become an increasingly important concern in science education because contemporary environmental challenges, including climate change, energy transition, and resource depletion, involve complex interactions among ecological, technological, economic, and social systems. Understanding these challenges requires more than the acquisition of isolated scientific concepts; students need to recognize relationships among system components, examine cause-and-effect processes, and consider the broader consequences of human activities on environmental sustainability. In this regard, systems thinking has emerged as an important competency for sustainability-oriented science education,

enabling learners to understand complex phenomena through their interconnected components and dynamic relationships (Onat et al., 2017; León & Calvo-Amodio, 2017; Skaržauskienė, 2010). Particularly in renewable energy education, students are expected to understand how energy resources, conversion processes, technological applications, and environmental impacts interact within broader sustainability systems.

Developing systems thinking, however, presents an educational challenge because understanding individual scientific concepts does not necessarily mean that students can integrate them into coherent explanations of complex environmental problems. Students may recognize renewable energy sources and understand basic energy conversion processes while experiencing difficulties explaining causal relationships, evaluating environmental consequences, and considering the long-term implications of energy technologies. This distinction highlights the importance of moving beyond conceptual knowledge toward the ability to interpret systems holistically. Previous research has emphasized the relevance of systems thinking for addressing complex sustainability challenges and improving the capacity to understand relationships within interconnected systems (Onat et al., 2017; León & Calvo-Amodio, 2017). Nevertheless, examining how students demonstrate these competencies in authentic renewable energy contexts remains important for identifying specific areas requiring educational attention.

This educational concern is particularly relevant to Islamic higher education. Islamic educational philosophy emphasizes the integration of scientific knowledge, ethical responsibility, and human accountability toward the natural environment. The concept of *khalifah fil ardh* positions human beings as stewards of the Earth, carrying responsibilities to maintain environmental balance and use natural resources responsibly. From this perspective, sustainability education should not be limited to understanding environmental processes as scientific phenomena but should also encourage students to recognize the consequences of human activities and develop scientifically informed responses to environmental challenges. A relevant educational challenge, therefore, is how to translate the ethical responsibility of environmental stewardship into science learning experiences that develop students' capacity to understand interconnected environmental systems. Systems thinking offers a conceptual perspective for addressing this challenge because it connects scientific reasoning with the ability to analyze environmental relationships, evaluate consequences, and consider sustainable solutions. However, the present study does not measure Islamic values or religious understanding directly; rather, it examines systems thinking within the broader educational context of Islamic environmental responsibility.

Renewable energy from agricultural biomass provides a meaningful context for examining these competencies. In Indonesia, rice husk represents an agricultural by-product with potential for conversion into alternative energy sources through thermochemical processes, including pyrolysis (Foo & Hameed, 2009; Kumar et al., 2013, 2016; Quispe et al., 2017; Gao et al., 2020; Unrean et al., 2018). Its utilization connects several dimensions of sustainability, including agricultural waste management, energy production, resource efficiency, environmental impacts, and technological development. The conversion of rice husk into alternative fuels also provides opportunities to discuss the relationship between renewable energy utilization and reduced dependence on fossil fuels (Chavan et al., 2024; Nawaz et al., 2023; Lubis, 2018). Therefore, rice husk biomass is not merely an example of an alternative energy resource; it represents an interconnected system through which students can examine relationships between scientific processes, technological applications, and environmental sustainability. These relationships are also relevant to the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (Nandiyanto et al., 2025; Mashhadi et al., 2024).

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Within this context, digital technologies, particularly the Internet of Things (IoT), offer possibilities for representing and monitoring technological processes in renewable energy systems. IoT enables interconnected devices to collect and exchange data, potentially supporting the observation of system conditions and relationships through real-time monitoring. Previous studies have discussed the potential application of digital technologies in education and the development of higher-order thinking skills (Lase, 2019; Tri et al, 2021; Shahroom & Hussin, 2018; Kwangmuang et al., 2021; Venkatraman et al., 2022; Al Farizi et al., 2024). Nevertheless, the educational value of technology depends not simply on its availability but on how learning activities encourage students to interpret information, understand relationships, and reason about complex processes. Accordingly, IoT is considered in this study as part of the technological context of renewable energy systems rather than as an instructional intervention whose effectiveness is being evaluated.

Although systems thinking has received attention in science and sustainability education, empirical evidence concerning students' ability to understand interconnected processes within authentic biomass-based renewable energy contexts remains limited. In particular, further investigation is needed to understand how Biology Education students demonstrate different dimensions of systems thinking when examining relationships among biomass resources, energy conversion, technological systems, and environmental sustainability. This issue is relevant to Islamic higher education because identifying students' strengths and difficulties in systems thinking can provide an empirical basis for designing science learning that connects scientific competence with environmental responsibility. Furthermore, assessment instruments need to be examined to determine whether they provide meaningful evidence of students' performance across different systems thinking dimensions. The Rasch measurement model offers an approach for examining item characteristics, response patterns, and the distribution of student abilities, thereby supporting the interpretation and refinement of educational assessment instruments.

Addressing these concerns, this study examines the systems thinking abilities of Biology Education students at Universitas Muhammadiyah Sukabumi in understanding renewable energy through the context of rice husk biomass. Specifically, it evaluates the preliminary measurement characteristics of a systems thinking assessment instrument and identifies students' performance profiles across six dimensions: identifying system components, understanding interconnections, cause-and-effect thinking, holistic thinking, dynamic thinking, and systemic problem solving. Using the Rasch measurement model, the study investigates item fit, reliability, item difficulty, dimensionality, and the distribution of students' abilities. Rather than evaluating the effectiveness of IoT-based learning media, this research provides preliminary empirical evidence about students' systems thinking performance and the measurement characteristics of the assessment instrument. Its contribution lies in extending the application of systems thinking assessment to a contextualized renewable energy problem while positioning sustainability-oriented science learning within the ethical perspective of environmental stewardship in Islamic higher education. The findings are expected to inform future instructional development that integrates scientific understanding, systems thinking, and environmental responsibility.

METHOD

This study uses a quantitative descriptive approach with Rasch model analysis (Chan et al., 2014). The study aims to describe the quality of the instrument and students' systems thinking skills in understanding IoT-based renewable energy from rice husk biomass. The participants were 19 students enrolled in the Biology Education Study Program at Universitas Muhammadiyah Sukabumi. Participants were selected using purposive sampling based on their

prior learning experience in renewable energy and environmental topics. This criterion was used to ensure that participants had sufficient conceptual background to engage with the systems-thinking tasks presented in the instrument. The study was designed as a preliminary measurement and needs-analysis study rather than as a large-scale validation study. Therefore, the sample was limited to students available and meeting the predetermined eligibility criteria during the data-collection period. The small sample should nevertheless be considered an important limitation because a larger and more heterogeneous sample would provide more stable estimates of person parameters and stronger evidence for the generalizability of the Rasch measurement results. Consequently, the findings are interpreted as preliminary evidence of students' systems-thinking profiles rather than as representative estimates for Biology Education students generally.

The systems-thinking instrument was developed through several conceptual stages. First, the researchers identified renewable energy from rice husk biomass as the contextual domain because it provides an interdisciplinary problem involving biomass resources, energy conversion, environmental impacts, technology, and sustainability. Second, the construct of systems thinking was operationalized through six dimensions: identifying system components, understanding interconnections, cause-and-effect thinking, holistic thinking, dynamic thinking, and systemic problem solving. These dimensions were derived from the systems-thinking literature cited in this study, including the work of Senge, Forrester, Ackoff, Richmond, and Cabrera and colleagues. Third, the dimensions were translated into learning indicators relevant to renewable energy and sustainability. Fourth, ten essay items were constructed to represent the relationships between the systems-thinking dimensions and the renewable-energy context. Finally, the items were subjected to Rasch analysis to examine their empirical measurement characteristics, including item fit, item difficulty, reliability, and dimensionality.

RESEARCH INSTRUMENT

The primary construct measured in this study is students' systems-thinking ability. Systems thinking is operationalized as the ability to identify components of a system, recognize and explain relationships among components, reason about cause-and-effect relationships, consider multiple dimensions of a system, anticipate changes over time, and formulate solutions that address the system as a whole. These dimensions were represented through six indicators: identifying system components, understanding interconnections, cause-and-effect thinking, holistic thinking, dynamic thinking, and systemic problem solving.

The renewable-energy context was used to make these systems-thinking processes observable within a meaningful science-learning problem. Rice husk biomass, bioenergy conversion, environmental sustainability, SDGs, fuel quality, sensors, and IoT were therefore treated as contextual knowledge domains rather than separate latent constructs. For example, an item concerning IoT was intended to assess students' ability to identify technological components and explain their relationships within an energy-monitoring system, rather than simply assess their ability to recall the definition or function of IoT.

Nevertheless, the researchers recognize the possibility of construct contamination. Some items, particularly those involving RON, sensor-based technology, and technological design, require domain-specific knowledge in addition to systems-thinking processes. Consequently, a low response on these items cannot be interpreted exclusively as evidence of weak systems thinking because it may also reflect limited prior knowledge of the relevant technical concepts. The Rasch results are therefore interpreted as evidence of students' systems-thinking performance within the specific context of renewable-energy learning, rather than as a context-independent measurement of systems thinking. This limitation is particularly relevant given the preliminary nature of the study and the small sample size. Future instrument

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development should use expert judgment, cognitive interviews, and pilot testing to distinguish more clearly between difficulties arising from systems-thinking processes and difficulties arising from insufficient domain knowledge.

Table 1 show instrument was a systems thinking ability. The instrument was structured based on the following system thinking dimensions: (i)Identifying system components; (ii) Understanding interconnections; (iii) Holistic thinking; (iv) Cause and effect thinking; (v) Syatemic problem solving; and (vi) Dynamic/systemic thinking. From six dimensions they are 10 questions essay about systems thinking ability test.

Table 1. Instrument research

No	System-thinking dimension	Contextual domain	What the student must demonstrate
1	Identifying system components	Rice husk biomass/bioenergy	Identify components and input-process-output relationships
2	Understanding interconnections	Biomass-environment energy	Explain relationships among biomass, energy and environment
3	Understanding interconnections	IoT energy monitoring	Explain relationships among hardware, software and monitoring
4	Holistic thinking	SDGs and renewable energy	Connect energy, environmental and sustainability dimensions
5	Cause-and-effect thinking	Biofuel vs fossil fuel	Explain environmental consequence
6	Cause-and-effect thinking	RON/fuel quality	Explain relationships between fuel characteristics and performance
7	Cause-and-effect thinking	Low-RON fuel	Explain consequences within the fuel-use system
8	Systemic problem solving	Sensor/IoT technology	Propose a solution considering system components
9	Holistic thinking	Sustainable energy technology	Develop a solution considering multiple system dimensions
10	Dynamic/systemic thinking	Digital transformation	Analyze potensial change in the nergy system

Table 2 shows the relevance of the questions to the indicators of systems thinking. There are six indicators of systems thinking derived from the theoretical perspectives of Peter Senge's concept of The Fifth Discipline, Derek Cabrera, Donella Meadows' Thinking in Systems, Jay Forrester, Russell Ackoff, and Barry Richmond (Arnolds & Wade, 2015; Senge & Sterman, 1992; Cabrera et al., 2023; Canty-Waldrom, 2014). These indicators include identifying system components, understanding interconnections, cause-and-effect thinking, holistic thinking, dynamic thinking, and systemic problem-solving.

This table explains the relationship between systems thinking skill indicators and relevant learning activities in the context of renewable energy and sustainability. Each indicator represents a specific thinking skill that research subjects are expected to demonstrate to understand a system as a whole rather than focusing only on its individual parts. Through these indicators, students are encouraged to recognize the relationships among system components, understand how changes in one component may affect others, and consider the broader implications for renewable energy and sustainability.

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Table 2. Relevance indicator system thinking.

Indicator system thinking	Indicator derivative	Relevance number questions	Ref.
Identifying System Components	Identify components in a renewable energy system Determine the system's input–process–output Identify the actors or technologies involved	1, 7, 8	(Kim & Senge, 1994; Senge & Sterman, 1992; Cabrera et al, 2023)
Understanding Interconnections	Explain the relationship between biomass, energy, the environment, and technology Connect the pyrolysis process to the carbon cycle Explain the relationship between sensors, IoT, and fuel quality	2,3,8,10	(Canty-Waldron, 2014; Senge & Sterman, 1992)
Cause and Effect Thinking	Explain the impact of biofuel use on the environment Explain the consequences of using low-RON fuels Predict the consequences of technology on energy sustainability	4,5,6	(Forrestes, 1994; Canty-Waldron, 2014)
Holistic Thinking	Connecting energy, economic, environmental, and technological aspects Assessing energy solutions multidimensionally Understanding the link between the SDGs and renewable energy	3,4,9	(Ackoff, 1994; Forrestes, 1994)
Dynamic Thinking)	Predicting the development of energy technology Analyzing the long-term sustainability of biofuels Understanding the digital transformation of the energy industry	9, 10	(Forrester, 1994; Barry Richmond, 1993)
Systemic Problem Solving	Designing an IoT-based RON detector Integrating hardware, software, and sensors Developing innovative energy technologies	7,8,9,10	(Cabrera et al, 2014; Senge & Sterman, 1992)

Construct Definition and Alignment of the Systems Thinking Instrument

The primary construct measured in this study is students' systems thinking ability in the context of renewable energy and sustainability. Systems thinking is defined as the capacity to understand a system through its constituent components, relationships, causal processes, dynamic behavior, and interactions across multiple dimensions, as well as to formulate solutions

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that address the system as a whole. In this study, the construct is operationalized through six interconnected dimensions: (1) identifying system components, (2) understanding interconnections, (3) analyzing causal relationships, (4) understanding dynamic relationships, (5) holistic reasoning, and (6) systemic problem solving. These dimensions draw on systems thinking perspectives associated with Senge, Forrester, Ackoff, Richmond, and Cabrera and colleagues.

The six dimensions provide a conceptual progression from recognizing individual elements of a system toward understanding and addressing its complexity. Identifying system components requires students to recognize the elements, processes, inputs, and outputs that constitute a renewable energy system. Understanding interconnections involves explaining how these components relate to and influence one another. Causal reasoning focuses on identifying how changes in particular components or processes produce consequences elsewhere in the system. Dynamic reasoning extends this understanding by examining how relationships and system conditions change over time. Holistic reasoning requires students to integrate scientific, environmental, technological, and sustainability perspectives, while systemic problem solving involves developing solutions that account for multiple interacting components and their potential consequences.

Rice husk biomass and renewable energy provide the contextual domain through which these cognitive processes are assessed. The contextual knowledge includes biomass resources, energy conversion, environmental sustainability, fuel characteristics, sensor technology, and the Internet of Things (IoT). These topics are not treated as independent constructs to be measured. Instead, they provide meaningful scientific situations in which students are required to demonstrate systems thinking. Consequently, the assessment focuses on how students identify, connect, analyze, predict, integrate, and solve problems involving the components of renewable energy systems, rather than merely recalling disciplinary definitions or technical information.

To strengthen the alignment between the construct and the assessment tasks, each essay item was mapped to a primary systems thinking dimension, an associated scientific context, and an expected cognitive operation. For example, an item concerning rice husk biomass is intended to assess students' ability to identify the components and input–process–output relationships of a biomass energy system rather than simply recall the definition of biomass. Similarly, an item concerning IoT-based energy monitoring assesses students' ability to explain the interactions among sensors, hardware, software, and monitoring processes rather than their ability to recall the functions of individual technological components. Questions involving fuel characteristics and RON are intended to assess causal reasoning concerning relationships between fuel properties and system performance, rather than isolated knowledge of fuel chemistry.

This distinction between the disciplinary context and the target cognitive construct is important because some assessment tasks require domain-specific scientific and technological knowledge in addition to systems thinking. In particular, questions involving RON, sensor-based monitoring, and technological design may introduce additional cognitive demands. Therefore, students' responses to these items should be interpreted in relation to their ability to demonstrate systems-level reasoning within the specified renewable energy context, rather than as context-independent measures of systems thinking.

The ten essay items were subsequently examined using the Rasch measurement model to investigate their empirical characteristics, including item fit, item difficulty, reliability, dimensionality, and response patterns. However, statistical fit alone does not establish comprehensive construct validity. The interpretation of the measurement results therefore considers the conceptual alignment between the assessment items and the six systems thinking dimensions, alongside the limitations associated with the preliminary sample and the potential influence of disciplinary knowledge. Further validation through expert judgment, cognitive

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interviews, and testing with larger and more diverse student populations is necessary to strengthen the validity evidence for subsequent applications.

DATA COLLECTION TECHNIQUES

Data were obtained by administering test instruments to biology students. Student responses were then analyzed using the Rasch model with the help of the Winsteps application. The analysis was conducted in several stages: (i) item validity analysis; (ii) instrument reliability analysis, (iii) item difficulty analysis, (iv) unidimensionality analysis; (v) person fit analysis; and (vi) Respondent ability analysis.

1. Item validity analysis

Table 3 presents the validity and suitability criteria for instrument items based on the Rasch Model approach. The Rasch Model is an analytical method in Item Response Theory (IRT) used to evaluate the quality of research instruments, particularly in educational measurement, psychology, and learning evaluation. This table serves to determine whether a question item is deemed appropriate for use, conforms to the measurement model, and measures the same construct as the instrument as a whole.

Table 3. Rasch Model Item Validity Criteria.

Aspect	Criteria	Interpretation
Outfit Mean Square (MNSQ)	0.5 – 1.5	Items are declared fit and productive for measurement.
Outfit Z-Standard (ZSTD)	-2.0 until +2.0	Items fit the Rasch model
Point Measure Correlation (Pt Measure Corr)	Positive value	Point Measure Correlation (Pt Measure Corr)

2. Instrument reliability analysis,

Table 4 presents instrument reliability criteria in educational measurement analysis and quantitative research, particularly those related to the Rasch Model and instrument internal consistency testing. This table is used to evaluate: (i) the level of data consistency; (ii) item quality; (iii) the instrument's ability to differentiate respondents' abilities; and (iv) the overall reliability of the measurement instrument. In general, the higher the reliability value, the better the quality of the research instrument.

Table 4. Rasch Model Reliability Criteria

Aspect	Reliability value	Interpretation	Reference
Person Reliability	< 0.67	Weak	Sumintono & Widhiarso (2015)
Person Reliability	0.67 – 0.80	Enough	Sumintono & Widhiarso (2015)
Person Reliability	0.81 – 0.90	Good	Sumintono & Widhiarso (2015)
Person Reliability	0.91 – 0.94	Very Good	Sumintono & Widhiarso (2015)
Person Reliability	> 0.94	Excellent	Sumintono & Widhiarso (2015)
Item Reliability	Closer 1.00	The better the quality of the item	Linacre (2012)

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Separation Index	> 2.00	Able to differentiate ability/difficulty groups	Boone et al. (2014)
Cronbach Alpha	> 0.70	Good internal reliability	Fraenkel et al., (2012)

3. Item difficulty analysis,

The difficulty level of an item in the Rasch model is determined based on the logit (measure) value. The higher the logit value, the more difficult the item is, while the smaller or negative the logit value, the easier the item is for respondents to answer (Boone et al., 2014; Sumintono & Widhiarso, 2015). Table 5 explains the item difficulty level criteria in the Rasch Model analysis based on logit values. In the Rasch Model, item difficulty is measured using logit units (log odds units), an interval scale that indicates an item's position in relation to the respondent's ability on the construct being measured. The logit value is an important indicator for determining whether an item is considered easy, moderate, or difficult for respondents to complete. The higher the logit value for an item, the more difficult it is, while a lower logit value indicates that the item is easier for respondents to answer.

Table 5. Item Difficulty Level Criteria

Logit Value Range	Interpretation
> +1.00 logit	Very difficult
0.01 until +1.00 logit	Difficult
around 0.00 logit	Medium
-1.00 until -0.01 logit	Easy
< -1.00 logit	Very easy

4. Unidimensonality analysis,

Unidimensionality is used to determine whether an instrument measures a single main construct. Analysis was performed using Principal Component Analysis (PCA) of Residuals. The Table 6 explains how an instrument is tested to ensure that all items measure the same latent construct (unidimensionality). In the Rasch Model, the assumption of unidimensionality is crucial because it requires that all items in an instrument represent only one primary latent variable. If an instrument measures more than one construct simultaneously, measurement validity can be compromised and the interpretation of results can be inaccurate. The first aspect of the table is Raw Variance Explained by Measures. A commonly used criterion is a minimum variance explained value of 20%, while a value above 40% is considered excellent. This percentage indicates how much of the data variance is successfully explained by the main constructs in the Rasch model. The higher the percentage of variance explained, the stronger the evidence that the instrument is unidimensional. If the variance explained value is low, there is a possibility that the items in the instrument measure more than one latent construct. Boone et al. (2014) explained that a high variance explained value indicates that the items work consistently in measuring the same construct.

Next, the table typically includes an Unexplained Variance in the First Contrast section. This section indicates the largest residual variance unexplained by the Rasch model. In unidimensionality analysis, the first contrast value should ideally be less than 15%. The smaller the unexplained variance value, the less likely it is that a second dimension exists in the instrument. If the first contrast value is too large, it indicates that groups of items may be measuring different constructs. This condition can violate the unidimensionality assumption and reduce the instrument's construct validity (Bond & Fox, 2015).

In addition, some unidimensionality tables also display the eigenvalues of the first contrast residuals. The eigenvalues are used to estimate the strength of the second dimension

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appearing in the residuals. In the Rasch Model, a residual eigenvalue below 2.0 is generally considered safe because it indicates that the additional dimension is not strong enough to be considered a new construct. Conversely, a high eigenvalue indicates the presence of other systematic patterns in the data that require further examination. Linacre (2012) stated that a low residual eigenvalue is an indicator that the instrument has a homogeneous construct structure.

Table 6. Criteria Unidimensionality Analysis

Aspect	Criteria	Reference
Raw Variance Explained by Measures	>20%	Linacre (2012)
Unexplained Variance in 1st Contrast	<15%	Boone et al. (2014)
Eigenvalue Contrast	<3.0	Sumintono & Widhiarso (2015)

5. Person fit analysis,

Per-person analysis was conducted to determine the consistency of respondents' answers, detect respondents who might answer inconsistently, and see the level of ability of each respondent based on the logit value. Table 7 about criteria person fit. Person fit analysis is used to identify respondents who have inconsistent answer patterns or are likely to answer unnaturally. Whereas, person fit analysis is obtained from the person fit order table to see respondents who have inconsistent answer patterns.

Table 7. Criteria Person Fit

Aspect	Criteria	Interpretation
Outfit Mean Square (MNSQ)	0,5 – 1.5	Respondents consistent
Outfit Z-Standard (ZSTD)	-2.0 sampai +2.0	Respondents fit the model
Point Measure Correlation	Positive value	Answer pattern according to construct

6. Respondent ability analysis.

Respondents' abilities are analyzed based on the logit value in the PERSON Measure Order table. The higher the logit value, the higher the respondent's ability. Table 8 shows the respondent ability criteria based on the logit values obtained from the Rasch model analysis. Logit values are used to describe a person's level of ability in answering or completing a measurement instrument. The higher the logit value, the higher the respondent's ability. Based on the table, respondents with a logit value greater than +1.00 are categorized as having very high ability, indicating they are able to answer items with a relatively high level of difficulty. Respondents with a logit value between 0.01 and +1.00 are categorized as having high ability, indicating they have above-average ability. Meanwhile, respondents with a logit value around 0.00 are categorized as having medium ability, indicating average ability that is balanced with the level of item difficulty.

Furthermore, respondents with logit values ranging from -1.00 to -0.01 are categorized as having low ability, indicating that their performance is below average and they may experience difficulties in answering certain items. Meanwhile, respondents with logit values below -1.00 fall into the very low category, suggesting that they have the lowest ability level among the groups and may struggle with most of the items in the instrument. These classifications provide an overview of the distribution of respondents' abilities and help identify differences in their performance when responding to the instrument. They also serve as a basis for interpreting the extent to which respondents have developed the skills being measured. Thus, this table provides a basis for classifying respondents' ability levels into five categories: very high, high, medium, low, and very low, according to their respective logit values.

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Table 8 Criteria Respondents ability

Logit range	Interpretation
> +1.00	Very high
0.01 until +1.00	High
arround 0.00	Medium
-1.00 until -0.01	Low
< -1.00	very low
Logit range	Interpretation
> +1.00	Very high

RESULTS AND DISCUSSION

1. Instrument Item Validity

Table 9 show the item-fit analysis indicated that seven of the ten items met all specified Rasch fit criteria. Items 4 and 7 demonstrated relatively low point-measure correlations (0.09 and 0.17, respectively), suggesting that their alignment with the overall measurement construct requires further examination. Item 6 exhibited mild misfit, with an Outfit MNSQ value of 1.56. These findings provide preliminary evidence of acceptable item functioning for most assessment tasks while identifying three items that require refinement. However, satisfactory item-fit statistics alone do not establish comprehensive construct validity.

Table 9. Rasch item Fit statistics for the systems thinking instrument.

Item	Outfit MNSQ	Outfit ZSTD	Pt Measure Corr	Interpretation
1	1.31	1.01	0.60	Fit
2	0.74	-0.66	0.72	Fit
3	0.86	-0.34	0.54	Fit
4	0.75	-0.60	0.09	need attention
5	0.84	-0.48	0.70	Fit
6	1.56	1.62	0.60	Mid misfit
7	0.85	-0.46	0.17	need attention
8	0.72	-0.97	0.30	Fit
9	1.11	0.38	0.27	Fit
10	0.95	-0.02	0.52	Fit

2. Instrument Reliability

The results of the reliability analysis show at Table 10. presents the reliability and separation indices obtained from the Rasch analysis. Item reliability was 0.95, with an item separation index of 4.46, indicating that the instrument distinguished different levels of item difficulty within the present sample. In contrast, person reliability was 0.59, and person separation was 1.19, indicating limited differentiation among students' estimated ability levels. Cronbach's Alpha (KR-20) was 0.64, suggesting relatively modest internal consistency. The contrast between item and person reliability is important for interpreting the findings. Although the instrument identified variation in item difficulty, it provided less consistent differentiation of individual student performance. Therefore, the results are more informative for identifying relatively challenging assessment tasks than for establishing reliable rankings of students' systems thinking abilities. The small sample size (n = 19) and relatively homogeneous participant characteristics may have contributed to the limited person separation.

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Table 10. Reliability value from output winsteps

Component	Value	Interpretation
Person Reliability	0.59	Weak
Item Reliability	0.95	Very good
Person Separation	1.19	Weak
Item Separation	4.46	Very good
Cronbach Alpha (KR-20)	0.64	Enough

3. Item Difficulty Level

The item difficulty estimates are presented in Table 11. The measures ranged from -0.84 to +1.53 logits, indicating variation in the difficulty of the assessment tasks. Item 9 had the highest difficulty measure (+1.53 logits), followed by Item 4 (+0.84 logits), Item 10 (+0.70 logits), and Item 5 (+0.10 logits). According to the classification criteria, Item 9 was very difficult, whereas Items 4, 10, and 5 were classified as difficult. The remaining items had negative measures and were classified as relatively easy. The difficulty distribution suggests that students encountered different levels of cognitive demand across the assessment tasks. Item 9, which involved developing a sustainable energy technology solution, required the integration of scientific, technological, and sustainability considerations. Items 4 and 10 involved evaluating environmental consequences and considering technological changes within energy systems. These tasks required students to consider relationships extending beyond individual scientific concepts. However, item difficulty represents the relative challenge of each task within this particular assessment and should not be interpreted independently as evidence of students' overall competence in a specific systems thinking dimension.

Table 11. Item measure (logit) difficulty level

Item	Measure (logit)	interpretation
9	1.53	Very difficult
4	0.84	Difficult
10	0.70	Difficult
5	0.10	Easy
7	-0.17	Easy
8	-0.27	Easy
1	-0.58	Easy
6	-0.60	Easy
3	-0.70	Easy
2	-0.84	Easy

Wright Map (Person-Item Map)

Figure 1 presents the Wright Map, which displays the distribution of student measures and item difficulty on a common logit scale. Student measures ranged from approximately -0.52 to +0.84 logits, while item difficulty ranged from -0.84 to +1.53 logits. Most items were positioned below or around the central distribution of student measures, whereas Item 9 was located substantially higher on the difficulty scale. This distribution indicates that several assessment tasks were relatively accessible to the participants, while tasks requiring more extensive integration of scientific, technological, and sustainability considerations presented greater challenges. Nevertheless, the Wright Map should be interpreted as a preliminary representation of student–item relationships. Given the relatively weak person reliability and separation indices, the observed distribution does not provide sufficiently strong evidence for making definitive comparisons among individual students.

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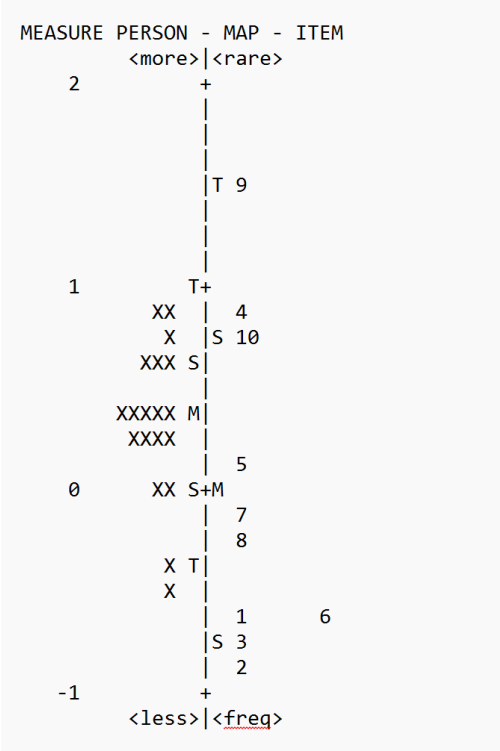


Figure 1. Wright Map (Person-Item Map)

4. Instrument Unidimensionality

Table 12. The Principal Component Analysis of Rasch residuals was used to examine the dominant measurement structure of the instrument. The analysis produced a raw variance explained by measures of 65.1%, an unexplained variance in the first contrast of 9.8%, and a first-contrast eigenvalue of 2.80. These values provide preliminary evidence that a dominant measurement dimension is represented in the response data. However, these results should be interpreted alongside the theoretical structure of the instrument, which includes six interconnected dimensions of systems thinking. The one-dimensionality result does not establish that the six dimensions have been independently validated or that all items are free from disciplinary knowledge influences. Further examination with a larger sample and additional construct-validity evidence is necessary to establish the measurement structure more robustly.

Table 12. Value Unidimensionalitas

Component	Value	Interpretation
Raw Variance Explained by Measures	65.1%	Very good
Unexplained Variance in 1st Contrast	9.8%	Good
Eigenvalue 1st Contrast	2.80	Accepted

The analysis results show that the Raw Variance Explained by Measures value is 65.1%, which means the instrument has a very good ability to explain the construct being measured. The Unexplained Variance in First Contrast value of 9.8% is still below the maximum limit of 15%, while the eigenvalue of 2.80 is still within acceptable limits. Therefore, the instrument meets the assumption of unidimensionality and can be stated to measure one dominant construct according to the Rasch model.

Per-person analysis was conducted to determine the consistency of respondents' answers, detect respondents who might answer inconsistently, and see the level of ability of each

respondent based on the logit value. Person fit analysis is used to identify respondents who have inconsistent response patterns or are likely to respond inappropriately. Respondents are considered fit if they meet the following criteria from Table 13 that summary of person fit analysis.

Table 13. Summary of Person Fit Analysis

Person Fit Classification	Number of respondents	Persentage (%)
Fit	11	57.9
Misfit	2	10.5
Need attention	2	10.5
Overfit	4	21.1
Total	19	100.0

Person-fit analysis was conducted to examine the consistency of students' response patterns with the Rasch measurement model. As presented in Table 13, 11 respondents (57.9%) demonstrated acceptable fit, while two respondents (10.5%) exhibited misfitting response patterns. Two additional respondents (10.5%) required further attention, and four respondents (21.1%) demonstrated overfitting patterns. These findings indicate that most respondents showed response patterns broadly consistent with the measurement model, although several deviations were observed. Misfitting responses may reflect unexpected response patterns, whereas overfitting responses indicate patterns that were more predictable than expected under the model. These classifications do not independently establish students' levels of systems thinking ability. Given the limited sample size and relatively low person reliability (0.59), the person-fit findings should be interpreted cautiously. Detailed respondent-level statistics are provided in Supplementary Table 13.

DISCUSSION

The results of this study indicate that students' systems thinking skills in understanding IoT-based renewable energy from rice husk biomass are in the fairly good category. The majority of the instrument items met the validity of the Rasch model and can therefore be used to measure students' systems thinking skills. Systems thinking skills are crucial in renewable energy learning because students must understand the relationship between biomass waste, energy conversion processes, environmental impacts, energy efficiency, and the sustainability of energy systems (González et al, 2016; Sunitiyoso et al., 2020; Laimon et al., 2022; Yılmaz & Selim, 2013; Kataya et al., 2023; Hammond, 2004). The use of rice husk as biofuel relates not only to energy technology but also to waste management, carbon emission reduction, and sustainable development (Chavan et al., 2024; Abbas & Ansumali, 2010; Ramírez et al., 2024).

The first important finding is the contrast between the strong item reliability (0.95) and relatively weak person reliability (0.59). The high item reliability indicates that the ten items produced a sufficiently differentiated hierarchy of difficulty within the present sample. In contrast, the weak person reliability indicates that the instrument was less successful in distinguishing individual students' ability levels.

This distinction is important for interpreting the findings. The study provides useful preliminary information about which systems-thinking tasks were relatively easy or difficult, but it provides less robust evidence for ranking students according to their overall systems-thinking ability. The person separation of 1.19 reinforces this interpretation because the observed sample does not provide strong differentiation among ability groups.

The result may partly reflect the small sample of 19 students and the relatively homogeneous educational background of the participants. Therefore, the finding that most

students were categorized as having high ability should not be interpreted as evidence of generally high systems-thinking competence. Instead, it indicates that most participants performed above the lower end of the item difficulty distribution in this particular assessment context.

From an educational measurement perspective, this finding emphasizes the importance of distinguishing between instrument functioning and student performance. The instrument appears more informative for identifying differences in item difficulty than for making strong claims about differences between individual students. Future studies should increase the sample size and include students with more heterogeneous backgrounds to obtain more stable person estimates.

The integration of IoT technology into learning provides opportunities for students to understand energy processes in real time through digital sensors and monitoring. The use of temperature sensors, density sensors, ESP32 microcontrollers, and cloud platforms can help students understand the biofuel production process more realistically and systematically (Caraveo Mena et al., 2025; Zambrano-Mieles et al., 2026).

The findings indicate that students demonstrate stronger performance in identifying renewable energy concepts than in explaining interactions among environmental, technological, and sustainability components. This pattern suggests that students possess foundational conceptual knowledge but require greater support in constructing holistic explanations of complex environmental systems. Within Islamic higher education, this finding is significant because sustainability education is expected to cultivate learners who can integrate scientific understanding with environmental responsibility. Consequently, systems thinking can function as a pedagogical bridge between scientific inquiry and the broader educational mission of preparing environmentally responsible graduates.

However, the low person reliability indicates that students' systems thinking skills are not evenly distributed. This suggests the need to develop more interactive IoT-based learning media to enable students to understand the relationships between energy system components in greater depth. Furthermore, the results also indicate that some items are classified as very difficult. This indicates that students still struggle to understand complex energy system analysis. Therefore, project-based learning and IoT simulations can be a solution to improve students' systems thinking skills.

CONCLUSION

This study provides evidence regarding the measurement of Biology Education students' systems thinking in the context of renewable energy and rice husk biomass sustainability. Rasch analysis indicates that the instrument demonstrates good item quality and acceptable unidimensionality, although person reliability suggests limited differentiation of student ability within the current sample. The findings show that students experience greater difficulty explaining complex interconnections among renewable energy, sustainability, and technological systems than identifying individual concepts. These results contribute to sustainability-oriented science education by identifying dimensions of systems thinking that require greater instructional attention in Islamic higher education. This study is limited by its small sample size (n = 19) and descriptive design, which restrict the generalizability of the findings and the stability of person reliability estimates. Future studies should involve larger and more diverse samples, strengthen construct validation, and investigate instructional approaches that explicitly foster systems thinking within sustainability-oriented science learning.

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