

Assessment of Sustainability Knowledge on Energy Issues : Development and Validation of an Instrument for Pre-Service Science Teachers

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ABSTRACT

This study aimed to develop and preliminarily validate an energy-issue-based sustainability knowledge assessment instrument for pre-service science teachers. Its novelty lies in contextualizing sustainability knowledge within authentic energy issues across environmental, economic, and social domains. The study employed an instrument development design with preliminary empirical testing involving 32 science education students in a single pilot administration. Data were analyzed using descriptive statistics, item difficulty, item discrimination, and KR-20 reliability. The findings indicated moderate student performance, better achievement on domain-specific than integrative items, and several items that were overly easy or showed weak discrimination. These results suggest that the instrument is potentially useful as a diagnostic tool in sustainability-oriented science education, although further refinement and broader validation are required.

INTRODUCTION

The accelerating climate crisis, resource insecurity, and widening social inequality have intensified expectations that higher education institutions embed sustainability more systematically in curricula, campus practices, and student learning agendas (Husic, 2024; Veidemane, 2022). Recent mapping studies show that Education for Sustainable Development (ESD) has expanded rapidly across higher education, with growing efforts to align curricula with the Sustainable Development Goals (SDGs) and to document this integration at program level (Adams et al., 2023; Yang & Xiu, 2023). However, the literature also indicates that progress in curricular integration has not been matched by equally robust, comparable, and context-sensitive assessment systems for measuring student sustainability learning outcomes (Concina & Frate, 2023; Veidemane, 2022).

Within this agenda, pre-service teachers are a strategically important population because their future classroom practice will shape how younger generations understand and respond to sustainability challenges (Parry & Metzger, 2023; Vidal & Kuckuck, 2025). Recent studies show that pre-service teachers often report positive orientations toward sustainability, yet their self-efficacy, content knowledge, pedagogical knowledge, and action competence remain unevenly developed across programs and contexts (Li, 2025; Nousheen et al., 2024; Vidal & Kuckuck, 2025). Related work also emphasizes that successful ESD implementation depends on clearer competency frameworks, stronger teacher preparation, and better assessment support for sustainability-oriented teaching and learning (Eliyawati et al., 2023; Günther et al., 2024).

A parallel issue concerns the substance of what students actually know, as recent sustainability literacy research has repeatedly shown that university students tend to understand sustainability primarily through environmental themes while giving less attention to social and economic dimensions (Chen et al., 2022; Erguvan, 2024). Systematic review evidence further suggests that many higher-education studies still prioritize attitudes and beliefs, often using heterogeneous questionnaires that make cross-study comparison and precise diagnosis of knowledge gaps difficult (Concina & Frate, 2023). Even when students are familiar with the language of sustainability, their literacy levels vary significantly by background, prior exposure, and learning context, indicating that familiarity with the concept does not automatically translate into integrated sustainability understanding (Cerović et al., 2024; Erguvan, 2024).

Energy provides a particularly productive context for sustainability assessment because energy decisions simultaneously involve environmental impacts, economic trade-offs, technological choices, and questions of equity, access, and social responsibility (Gladwin & Ellis, 2023; Santillán & Cedano, 2023). Recent energy literacy research likewise shows that students' cognitive, affective, and behavioral understandings of energy are often uneven, while instrument-development studies continue to call for valid tools that can assess knowledge and sustainability-related perceptions in context-sensitive ways (Acosta-Banda et al., 2021; Cerović et al., 2024; Ramachandran et al., 2024). From a science education perspective, this is important because critical science education for sustainability requires learners to reason with evidence about

socio-scientific issues, evaluate systemic interconnections, and consider justice-oriented implications of science and technology choices (Freitas et al., 2022; Ramachandran et al., 2024).

Although recent studies have advanced instruments for assessing science teacher competence to teach ESD, relatively few tools focus specifically on measuring sustainability knowledge through contextualized energy issues for pre-service science teachers (Eliyawati et al., 2023; Vidal & Kuckuck, 2025). This gap is consequential because pre-service science teachers need assessment experiences that mirror the kinds of judgments they will eventually make in classrooms when discussing fossil fuels, renewable energy, air pollution, energy justice, and transitions toward lower-carbon systems (Freitas et al., 2022; Gladwin & Ellis, 2023; Santillán & Cedano, 2023). Accordingly, the present study aims to develop and validate an energy-issue-based sustainability knowledge assessment instrument for pre-service science teachers that can support both educational evaluation and research on sustainability learning in science teacher education (Acosta-Banda et al., 2021).

THEORETICAL REVIEW

Sustainability Knowledge as a Multidimensional Construct

Recent studies on sustainability literacy consistently show that sustainability-related understanding should not be reduced to environmental awareness alone, because meaningful sustainability learning also requires economic and social understanding (Chen et al., 2022). Empirical work with university students has shown that learners often demonstrate uneven sustainability literacy, with stronger recognition of environmental issues than of social and economic dimensions, which suggests the need for more balanced assessment tools (Chen et al., 2022; Concina & Frate, 2023).

Instrument-focused studies likewise emphasize that sustainability-related constructs should be operationalized through clearly defined dimensions so that student understanding can be assessed more precisely and interpreted more validly in educational settings (Eliyawati et al., 2023; Salahange et al., 2024a). From this perspective, sustainability knowledge can be viewed as a contextualized cognitive construct that involves understanding interrelationships among environmental integrity, economic consequences, and social justice within concrete sustainability problems (Chen et al., 2022; Freitas et al., 2022).

Sustainability in Science Teacher Education

The literature on teacher education further shows that pre-service teachers are a crucial target group for sustainability research because their future professional decisions will influence how sustainability is interpreted and taught in schools (Duifhuis et al., 2025; Vidal & Kuckuck, 2025). Recent research indicates that pre-service science teachers often support sustainability-oriented education, yet they may also experience tensions related to disciplinary boundaries, value-laden content, and uncertainty about how to address complex socio-scientific issues in the classroom (Anor, 2024; Duifhuis et al., 2025). Studies

on science teacher competency for ESD therefore argue that teacher education requires assessment tools that are not only theoretically grounded but also pedagogically relevant to science learning contexts (Eliyawati et al., 2023; Freitas et al., 2022). This argument is reinforced by recent evidence showing that sustainability-focused interventions can influence pre-service teachers' dispositions and willingness to act, which further highlights the importance of identifying their knowledge base through valid instruments (Khazen et al., 2025).

Energy Literacy as a Relevant Context for Assessing Sustainability Knowledge

Energy issues provide a highly relevant context for sustainability assessment because they naturally connect environmental impacts, economic trade-offs, and social implications within a single decision-making space (Ramachandran et al., 2024; Santillán & Cedano, 2023). Recent reviews describe energy literacy as a growing field in education that goes beyond technical knowledge of energy systems and includes understanding energy use, energy transition, policy implications, and citizen engagement. This makes energy-related issues particularly suitable for assessing sustainability knowledge because students are required to evaluate trade-offs among emissions, efficiency, cost, access, public health, and long-term sustainability consequences (Freitas et al., 2022). For pre-service science teachers, the energy context is especially appropriate because it reflects the kinds of authentic socio-scientific issues they are likely to encounter in science teaching, such as fossil fuel use, renewable energy adoption, pollution, energy justice, and transportation transition (Anor, 2024; Duifhuis et al., 2025)

Assessment and Instrument Development in Sustainability Education

Recent assessment literature emphasizes that the quality of sustainability education depends in part on the availability of instruments that can diagnose students' knowledge, perceptions, and competences with adequate validity and reliability (Eliyawati et al., 2020; Salahange et al., 2024a). Instrument development studies in ESD and sustainability education commonly underline the importance of aligning item construction with a clear theoretical structure, specifying measurable dimensions, and conducting empirical testing to identify items that function well in practice. Similarly, work in critical science education for sustainability has highlighted that assessment should reflect complexity, contextual reasoning, and the capacity to engage with interdisciplinary sustainability problems rather than isolated factual recall alone (de Freitas et al., 2022; Ramachandran et al., 2024). Taken together, these studies suggest that an assessment instrument for pre-service science teachers should be theoretically multidimensional, contextually authentic, and empirically examined through pilot testing before wider implementation.

Contextual Framework of the Present Study

Based on the reviewed literature, the present study positions sustainability knowledge as the central construct and conceptualizes it as knowledge expressed through three interrelated domains, namely environmental, economic, and social dimensions of sustainability (Chen et al., 2022; Salahange et al., 2024a). The study

further assumes that energy-related issues provide an authentic and educationally meaningful context through which those three dimensions can be assessed in a more integrated way among pre-service science teachers (Ramachandran et al., 2024; Santillán & Cedano, 2023). Accordingly, the instrument in this study is designed to include both domain-specific items and integrative items, so that students' sustainability knowledge can be captured not only within separate dimensions but also across interconnections among them in real-world energy contexts (Eliyawati et al., 2023; Freitas et al., 2022). Because this research focuses on instrument development and preliminary validation, the study does not formulate causal hypotheses, but instead proposes a contextual framework in which energy-based sustainability knowledge is assessed through the environmental, economic, and social domains among pre-service science teachers.

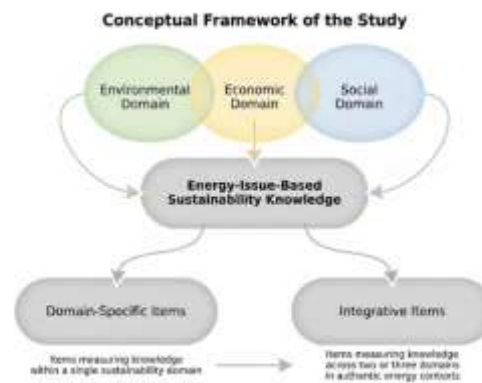


Figure 1. The construct is conceptualized through environmental, economic, and social domains and operationalized through domain-specific and integrative items

METHODOLOGY

Research Design

This study employed a research and development approach with a preliminary empirical validation stage to develop an assessment instrument of sustainability knowledge based on energy-related issues for pre-service science teachers. The instrument framework was adapted from the Assessment of Sustainability Knowledge (ASK) proposed by Zwickle and Jones, which conceptualizes sustainability knowledge across the environmental, economic, and social domains. In this study, the construct was contextualized into energy-related issues that are relevant to science education, such as fossil and renewable energy sources, energy efficiency, pollution, energy access, and transportation transition.

Participants

The population of this study was pre-service science teachers enrolled in a Science Education program. The pilot testing involved 32 students who completed the instrument. These participants were selected as the initial

respondents to examine the empirical performance of the developed items before broader administration.

Instrument

The instrument consisted of 15 multiple-choice items. It included domain-specific items representing the environmental, economic, and social dimensions of sustainability, as well as integrative items combining two or three dimensions within authentic energy-related contexts. The instrument blueprint was designed by adapting the sustainability knowledge framework of Zwickle and Jones and then aligning it with the needs of science teacher education. Each item had one correct answer and was scored dichotomously, with 1 for a correct response and 0 for an incorrect response. Therefore, the possible total score ranged from 0 to 15.

Data Collection

Data were collected through a pilot administration of the instrument to the selected participants. Students were asked to answer all 15 multiple-choice questions individually. The collected responses were then tabulated and converted into dichotomous scores for analysis.

Data Analysis

The data were analyzed using descriptive statistics and classical item analysis. Descriptive statistics were used to summarize students' performance in terms of the mean, standard deviation, minimum score, and maximum score. At the item level, the proportion of correct responses was used to identify item difficulty, while item discrimination was examined through the relationship between each item score and the total test score. Since the instrument used dichotomous scoring, internal consistency reliability was estimated using the Kuder-Richardson Formula 20 (KR-20). These analyses were intended to provide preliminary evidence of the empirical quality of the instrument and to identify items that may need revision before wider use.

RESULTS

The preliminary empirical testing of the instrument was conducted with 32 pre-service science teachers. Overall, the students showed a moderate level of performance on the developed test. As presented in Table 1, the mean total score was 10.75 out of a possible 15 points, with a standard deviation of 1.88. The scores ranged from 8 to 15, indicating that the students' performance was concentrated within a relatively narrow range. The internal consistency coefficient was $KR-20 = .31$, suggesting that the instrument, in its current pilot form, still requires revision before wider implementation. This overall score pattern is also illustrated in Figure 2, which shows that most students' scores clustered between 9 and 12.

Table 1. Descriptive Statistics of Students' Total Scores

Statistic	Value
Number of respondents	32

Number of items	15
Mean	10.75
Standard deviation	1.88
Median	11.00
Minimum	8
Maximum	15
KR-20	0.31

As shown in Table 1, the average score indicates that the respondents were able to answer a substantial proportion of the items correctly, although the relatively low KR-20 value suggests limited internal consistency at this stage of development. In addition, the concentration of scores around the middle-to-upper range indicates that several items may have been too easy for the pilot sample.

The distribution of total scores is presented in Figure 2. The figure confirms that the majority of respondents obtained scores in the middle range, with only a few students reaching the highest scores. This distribution suggests that the instrument was able to capture some variation in students' sustainability knowledge, although the spread remained relatively limited.

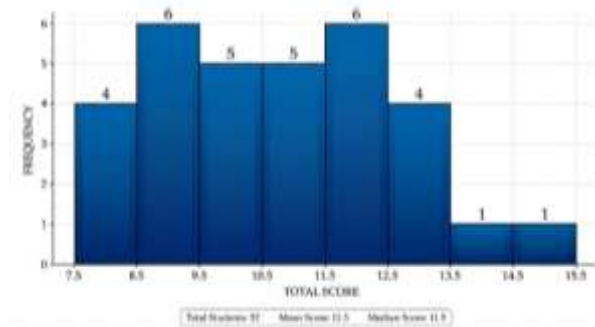


Figure 2. Distribution of Students' Total Scores

Item-level analysis is presented in Table 2. The proportion of correct responses shows that five items were categorized as very easy, namely S1, S2, S4, S6, and S7. In particular, S7 was answered correctly by all respondents. The remaining ten items fell into the moderate category, with proportions correct ranging from .50 to .69. The corrected item-total correlations indicate that S3, S8, and S9 were the most discriminating items in this pilot dataset, whereas S4, S6, and S13 showed negative values and should therefore be reviewed in future revisions.

Table 2. Item Analysis Results

Item	Proportion Correct	Difficulty Category	Corrected Item-Total Correlation
S1	0.94	Very easy	0.04
S2	0.97	Very easy	0.08
S3	0.53	Moderate	0.24
S4	0.97	Very easy	-0.02

S5	0.56	Moderate	0.06
S6	0.97	Very easy	-0.12
S7	1.00	Very easy	—
S8	0.59	Moderate	0.23
S9	0.69	Moderate	0.22
S10	0.59	Moderate	0.00
S11	0.69	Moderate	0.10
S12	0.50	Moderate	0.07
S13	0.69	Moderate	-0.01
S14	0.53	Moderate	0.12
S15	0.53	Moderate	0.08

Note. The corrected item–total correlation for S7 could not be estimated because all respondents answered the item correctly.

As presented in Table 2, the item difficulty pattern indicates that the pilot instrument contained a number of items that were too easy for the respondents, especially in the domain-specific section. At the same time, several moderate items showed better discrimination and may therefore serve as stronger candidates for retention in future revisions. The negative corrected item–total correlations found in several items suggest that further revision is needed in terms of item wording, distractor quality, or alignment with the intended construct.

To examine how students performed across the content structure of the instrument, the results were grouped by item category. As shown in Table 3, students performed better on domain-specific items than on integrative items. The highest percentage of correct responses was found in the economic domain-specific items (83.33%), followed by the environmental domain-specific items (81.25%) and the social domain-specific items (76.04%). In contrast, the integrative items produced the lowest average performance, with only 58.85% correct responses. This finding suggests that students found it more difficult to answer questions requiring them to connect multiple sustainability dimensions in authentic energy-related contexts.

Table 3. Students' Performance by Item Category

Category	Number of Items	Mean Score	Maximum Score	Percent Correct
Environmental domain-specific	3	2.44	3	81.25
Economic domain-specific	3	2.50	3	83.33
Social domain-specific	3	2.28	3	76.04
Integrative items	6	3.53	6	58.85

The pattern in Table 3 is visually supported by Figure 3, which displays the proportion of correct responses for each item. The figure shows that the highest-performing items were concentrated among the easier, mostly domain-specific

questions, whereas lower-performing items were more common among the integrative items. This result indicates that the integrative component of the instrument may be more sensitive for identifying differences in sustainability knowledge, although these items may still require refinement to improve discrimination.

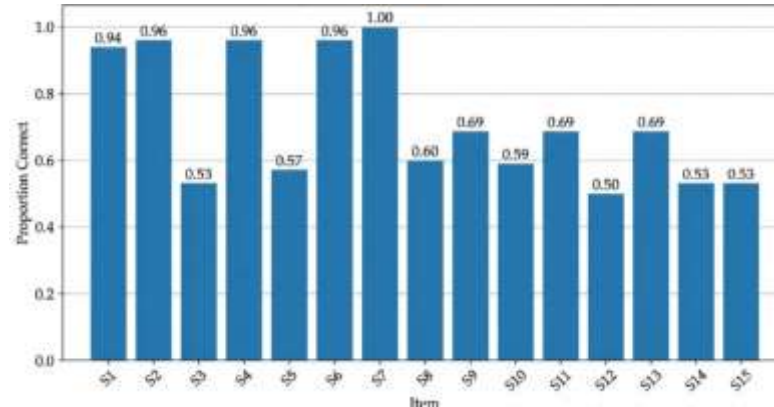


Figure 3. Item Difficulty Based on the Proportion of Correct Responses

Overall, the pilot findings indicate that the developed instrument has the potential to assess sustainability knowledge in energy-related contexts, but the empirical evidence also points to the need for further revision. Specifically, some items should be revised because they were too easy, one item showed no response variation, and several items displayed weak or negative item-total correlations. Nevertheless, the lower performance on integrative items suggests that the instrument was able to reveal a meaningful pattern in which students were more successful in answering single-domain questions than in addressing more complex sustainability issues involving multiple domains.

DISCUSSION

As presented in Table 1 and Figure 2, the respondents achieved a moderate level of performance, with a mean score of 10.75 out of 15, and their scores were concentrated within a relatively narrow range. This result suggests that the pre-service science teachers had acquired a basic understanding of sustainability knowledge in energy-related contexts, but their knowledge was not yet strongly differentiated across the full range of the instrument. Such a pattern is consistent with recent studies showing that university students often demonstrate moderate sustainability literacy, while their understanding remains uneven in depth and breadth across different sustainability dimensions and learning contexts (Chen et al., 2022; Concina & Frate, 2023; Erguvan, 2024). The finding also aligns with recent research in teacher education indicating that pre-service teachers may show positive orientations toward sustainability, but still require stronger knowledge structures to support meaningful ESD-related reasoning and future classroom practice (Duifhuis et al., 2025; Vidal & Kuckuck, 2025).

At the same time, Table 1 shows that the pilot instrument yielded a relatively low internal consistency ($KR-20 = .31$), indicating that the current version of the instrument is still in a preliminary stage of development. This result suggests that the instrument should not yet be interpreted as a finalized measure, but rather as

an early version that has begun to reveal useful patterns while still requiring psychometric improvement. A plausible explanation for this low reliability can be seen in Figure 2 and Table 2, where the score spread was limited and several items were found to be very easy. Recent instrument-development studies have shown that the reliability of educational assessments is often weakened when items are insufficiently discriminating or when respondents' scores cluster too closely together, especially during early pilot testing stages (Eliyawati et al., 2023; Salahange et al., 2024a). Therefore, the present result is still reasonable within the context of initial instrument development and should be treated as a basis for revision rather than as a final psychometric judgment.

The item-level findings in Table 2 and Figure 3 further clarify this pattern. Five items were categorized as very easy, and one item (S7) was answered correctly by all respondents, which means that this item contributed very little to distinguishing between higher- and lower-performing students. On the one hand, this may indicate that several basic sustainability concepts in energy-related issues were already familiar to the participants, especially those linked to everyday experiences such as efficiency, access, or obvious environmental impacts. This interpretation is supported by recent energy literacy research showing that students tend to engage more easily with concrete and familiar energy issues than with abstract systemic reasoning (Cerović et al., 2024; Ramachandran et al., 2024). On the other hand, some items in Table 2 also showed weak or even negative corrected item-total correlations, suggesting that certain stems or distractors may not have functioned effectively. This is consistent with recent psychometric studies indicating that weak distractors and overly easy items can reduce the discrimination power of multiple-choice tests and should be revised in later validation stages (Iñarrairaegui et al., 2022; Rezigalla et al., 2024).

A particularly important result appears in Table 3, which shows that students performed better on domain-specific items than on integrative items. The economic domain-specific items had the highest percentage of correct responses (83.33%), followed by the environmental domain-specific items (81.25%) and the social domain-specific items (76.04%), whereas the integrative items produced the lowest average performance (58.85%). This pattern suggests that the respondents were more capable of answering questions framed within a single sustainability dimension than questions requiring them to connect environmental, economic, and social considerations simultaneously. Such a result is highly relevant because recent sustainability literacy studies have similarly shown that students often understand sustainability in partial or segmented ways rather than as an interconnected multidimensional construct (Chen et al., 2022; Concina & Frate, 2023). From the perspective of science education, this is also significant because critical science education for sustainability emphasizes the importance of cross-domain reasoning, socio-scientific judgment, and the ability to evaluate trade-offs in real-world situations (Freitas et al., 2022).

Overall, the combined findings in Tables 1–3 and Figures 2–3 indicate that the developed instrument already has substantive value as a diagnostic tool, even though it still requires revision before wider use. The instrument was able to reveal a meaningful pattern in which pre-service science teachers performed better on

more direct, single-domain sustainability questions than on integrative items involving more complex energy-related trade-offs. This suggests that the instrument has promise for identifying areas in which students' sustainability knowledge is still developing, particularly in relation to integrated reasoning across environmental, economic, and social domains. At the same time, the low reliability and the presence of several overly easy items indicate that revision is necessary to improve item difficulty, distractor quality, and overall score consistency. This conclusion is consistent with recent studies in ESD and sustainability assessment, which emphasize that strong instruments are typically produced through repeated cycles of conceptual design, pilot testing, item revision, and broader empirical validation (Eliyawati et al., 2023; Salahange et al., 2024b; Vidal & Kuckuck, 2025).

CONCLUSIONS AND RECOMMENDATIONS

This study developed an energy-issue-based sustainability knowledge assessment instrument for pre-service science teachers by adapting the sustainability knowledge framework into the environmental, economic, and social domains within authentic energy contexts. The preliminary findings showed that the instrument has potential as a diagnostic tool for identifying students' sustainability knowledge in science education. The respondents achieved a moderate level of performance, with a mean score of 10.75 out of 15, indicating that they were able to answer a substantial proportion of the items correctly. However, the pilot results also revealed that the current version of the instrument still requires improvement. Several items were found to be too easy, one item showed no response variation, and the internal consistency coefficient ($KR-20 = .31$) was still low for wider implementation. In addition, students performed better on domain-specific items than on integrative items, suggesting that they were more successful in addressing sustainability issues within a single domain than in connecting environmental, economic, and social dimensions simultaneously.

Based on these findings, it is recommended that the instrument be revised and retested before being used more broadly. Item revision should focus particularly on overly easy items, weak distractors, and items with low or negative item-total correlations in order to improve the discriminative power and reliability of the test. Future studies should also involve a larger and more diverse sample to provide stronger empirical evidence for the instrument's validity and reliability. In addition, science teacher education programs should pay greater attention to strengthening students' ability to respond to integrative sustainability problems, especially those related to energy transition, environmental impact, economic trade-offs, and social justice. Thus, this study recommends the continued development of authentic issue-based sustainability assessments as part of efforts to improve sustainability-oriented science education for future teachers.

FURTHER STUDY

This study has several limitations that should be acknowledged. First, the instrument was tested only in a small pilot sample of 32 pre-service science teachers, which limits the generalizability of the findings. Second, some items

were found to be too easy, and the overall internal consistency was still low, indicating that the current version of the instrument requires further refinement. Third, the study relied on preliminary empirical testing, so stronger evidence of construct validity has not yet been established. Therefore, further studies are recommended to revise problematic items, involve larger and more diverse samples, and apply more advanced validation procedures to strengthen the psychometric quality of the instrument. Future investigations may also explore the use of this instrument in different educational contexts and examine its relationship with other variables, such as sustainability attitudes, energy literacy, and socio-scientific reasoning.

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