

Pre-Analysis of Literacy for Sustainability with Learning for Sustainability Assessment

Harlinda Syofyan¹, Budi Tjahjono², Oktian Fajar Nugroho³, Fitri Nuraeni⁴

Universitas Esa Unggul ^{1,2,3}

Universitas Pendidikan Indonesia⁴

Email Correspondence: sofilynda@esaunggul.ac.id

Abstract

This study analyzed students' sustainability literacy using a four-dimensional progressive scale: Non-Awareness, Awareness, Responsibility, and Taking on Leadership Role. Data from 50 students revealed a bimodal distribution, with highest concentrations at the Awareness stage (38%) and Leadership stage (40%), while only 20% were at Responsibility and 2% at Non-Awareness. This indicates a significant gap in sustainability learning progression, where transition from awareness to responsibility does not occur linearly. The high proportion at leadership level demonstrates great potential for developing sustainability change agents, but low representation at responsibility stage highlights the need for reformulated pedagogical strategies. These findings align with recent research showing sustainability literacy develops non-sequentially and requires specific interventions at transition stages. The study recommends developing experiential and project-based learning programs to strengthen the Responsibility stage, alongside a holistic approach integrating environmental, social, and economic domains to address complex future sustainability challenges.

Keywords: Sustainability Literacy; Analysis; Progressivity Of Learning; Assesment; Continuing Education

Introduction

The increasingly complex global environmental crisis demands fundamental transformation in higher education, particularly in developing students' sustainability literacy as future leaders. Sustainability literacy encompasses more than just a conceptual understanding of environmental, social, and economic issues. (Maulana et al., 2024), but also the ability to take concrete action in addressing sustainability challenges. In the context of achieving the 2030 Sustainable Development Goals (SDGs), higher education plays a crucial role in preparing graduates with the competencies needed to address complex socio-ecological challenges. (Chien & Chien, 2025); (Ekawati et al., 2025).

Recent research shows that there is still a significant gap between theoretical awareness and practice of sustainability among students. (Ekawati et al., 2025). According (Saifana Iluj' Dhia Hakiki & Diki Anggi Saputra, 2024) identified that nearly half of the sustainability literacy assessment instruments used in higher education research lacked adequate piloting and validation processes. Furthermore, a study by (Leal et al., 2024) emphasizes the importance of a hybrid approach that integrates formal, informal, and non-formal learning experiences in developing sustainable development competencies..

The Learning for Sustainability Assessment offers a comprehensive framework for measuring the development of sustainability literacy through four progressive stages: Non-Awareness, Awareness, Responsibility, and Taking on a Leadership Role. (Diamond & Irwin, 2013). This framework allows for the identification of not only students' current literacy levels, but also transition patterns and barriers to learning progression (Uzorka et al., 2024). The importance of sustainability literacy is increasingly prominent considering that higher education institutions are responsible for shaping future decision-makers and leaders. (Nugraha et al., 2023).

Literature Review

The Concept of Sustainability Literacy in a Contemporary Context

Sustainability literacy has evolved into a more complex and multidimensional concept in the last decade. Working of (Chen et al., 2022) defines sustainability literacy as the integration of knowledge, attitudes, and behaviors that support sustainable development. This definition expands the traditional understanding that focuses solely on the cognitive dimension by integrating the affective and behavioral dimensions, which are equally important in driving sustainable transformation. (Mróz & Ociekiewicz, 2024).

The sustainability competency framework developed by (Redman et al., 2021) and updated identifies five interrelated core competencies: systems-thinking competency, anticipatory competency, normative competency, strategic competency, and interpersonal competency. The study by (Amprazis & Papadopoulou, 2025) adding that these competencies encompass not only cognitive and technical dimensions, but also transformative dimensions that facilitate changes in students' perspectives and values. This approach recognizes that sustainability literacy is not simply the accumulation of knowledge, but involves a fundamental transformation in how individuals view their relationship to socio-ecological systems. The developed sustainability competency framework identifies three main competency categories: cognitive, metacognitive, and socio-communicative, which are essential for students to apply their knowledge and skills in professional contexts. (Nugraha et al., 2023). The development of sustainability literacy also includes the ability to think systems, think forward, think values, think strategically, and interpersonal competencies which are key in overcoming complex problems (Redman et al., 2021).

The GreenComp framework groups these competencies into four interconnected areas: "realizing sustainability values," "embracing complexity in sustainability," "imagining sustainable futures," and "acting for sustainability." (Persano Adorno et al., 2025). Cognitive and technical dimensions, but also a transformative dimension that facilitates changes in students' perspectives and values. This approach recognizes that sustainability literacy is not simply the accumulation of knowledge, but involves a fundamental transformation in how individuals view their relationship to socio-ecological systems (Ramadhani & Sunarya, 2024).

Progressive and Transformative Model of Sustainability Learning

Recent research on sustainability learning emphasizes the importance of transformative approaches that go beyond conventional knowledge transmission. Transformative learning in the context of sustainability involves a process of in-depth critical reflection, meaningful concrete experiences, and the development of student agency as agents of change. This model recognizes that literacy development is not always linear and can involve 'threshold moments' or points of transformation that fundamentally change how students understand and interact with sustainability issues.

Recent research on sustainability learning emphasizes the importance of transformative approaches that go beyond conventional knowledge transmission. This aligns with the concept of education for sustainable development, which focuses on acquiring skills, competencies, and knowledge to proactively change economic, ecological, and social behavior (Mulyadiprana et al., 2022). Therefore, the development of sustainability literacy must include the ability to identify, analyze, and evaluate environmental problems based on ecological and socio-political foundations, in addition to fostering an attitude of empathy and concern for the environment. (Santiani et al., 2023). Critical thinking skills related to the environment are an important prerequisite for developing environmental awareness and literacy, helping students understand the complexity of sustainability issues and (Widiyastuti et al., 2024).

This model recognizes that literacy development is not always linear and can involve 'threshold moments' or points of transformation that fundamentally change how students understand and interact with sustainability issues. Study (Priyanka et al., n.d.) identified four pedagogical principles that characterize effective sustainability learning: contextual learning (learning based on real contexts), constructive learning (active knowledge construction), collaborative learning (interdisciplinary collaboration), and transformative learning (transformation of perspectives and values). Their research shows that experiential learning approaches such as problem-based learning, project-based learning, and challenge-based learning are highly effective in facilitating students' transition from awareness to responsibility and leadership. However, implementing these approaches requires appropriate scaffolding and adequate institutional support to address the complexity and uncertainty inherent in sustainability issues.

In this regard, universities need to expand existing educational programs and implement new initiatives that go beyond conventional practices to equip students with the competencies necessary for sustainable development at every level of education (Idoiaga, Mondragon et al., 2023). Involving varied teaching methods such as inquiry-based, collaborative, project-based, and hands-on learning is also essential to enrich students' environmental literacy (Zulfah et al., 2024).

Sustainability Literacy Measurement and Assessment Instrument

The development of valid and reliable instruments to measure sustainability literacy has become a research priority in Education for Sustainable Development (ESD). They reviewed various assessment instruments and identified two main approaches: adaptation and modification of existing research instruments, and the use of publicly available sustainability tests such as the Sulitest (Sustainability Literacy Test). They found that the Sulitest, developed as a 30-minute multiple-choice assessment to measure minimum knowledge of economic, social, and environmental responsibility, is one of the most comprehensive instruments available. (Décamps et al., 2017).

However, in the research (Yanti et al., 2025) also identified a critical gap in sustainability literacy assessment research: the lack of a rigorously validated universal sustainability literacy test. They found that nearly half of the instruments reviewed in their study had not undergone adequate piloting and validation, indicating a significant methodological weakness (Martin et al., 2025). These findings reinforce the urgency of developing more robust, reliable, and valid instruments for measuring sustainability literacy. A recent study from (Kuehl et al., 2023) reported the implementation of an inaugural sustainability literacy assessment for their undergraduate population with a median score of 71%, demonstrating the importance of continuous assessment in tracking students' sustainability literacy development.

The Higher Education Sustainability Initiative (HESI), launched in 2025, emphasized the importance of 'frameworks to practice' for sustainability competencies. The initiative identified that despite the development of various competency frameworks (the UNESCO Competency Framework, the EU Green Comp Framework, and various national/sectoral frameworks), there remains a lack of awareness and adoption, hindering the practical implementation of the pedagogical and curricular changes necessary to develop these competencies. (Chien & Chien, 2025; Lozano et al., 2023).

Methodology

Research Design

This study used a quantitative approach with a cross-sectional survey design to analyze the distribution of students' sustainability literacy levels. This method was chosen because of its ability to measure population characteristics at a single point in time and identify distribution patterns that can inform pedagogical interventions. The quantitative approach allows for comprehensive statistical analysis of sustainability literacy data and identification of the significance of the patterns found, in line with best practices in sustainability literacy assessment research (Miterianifa & Mawarni, 2024).

Participants

The research sample consisted of 50 students from various PGSD study programs at Esa Unggul University who had studied the concept of science by integrating sustainability education into the curriculum. Participants were selected using a purposive sampling technique with the criterion of having taken at least one sustainability-related course. The distribution of participants spanned various academic levels (1st to 4th year) to capture variations in exposure to sustainability education. The diversity of academic backgrounds allowed for a more comprehensive analysis of the development of sustainability literacy across various learning contexts, following recommendations from recent studies that emphasize the importance of representative sampling in sustainability assessment (Bitar & Davidovitch, 2024).

Research Instruments

The Learning for Sustainability Assessment instrument used in this study consists of 50 items designed to measure four progressive stages of sustainability literacy. Each item was developed based on theoretical and empirical literature on sustainability learning, including the competency framework developed by the (Compan et al., 2025). The instrument uses a 5-point Likert scale (strongly disagree to strongly agree) to measure respondents' level of agreement with each statement.

Instrument validation was conducted in two stages: content validity and construct validity. Content validity was evaluated by an expert panel consisting of three academics with expertise in sustainability education. Construct validity was analyzed using confirmatory factor analysis to ensure that the instrument items measured the intended constructs. Of the initial 50 items, 47 (94%) were declared valid based on the criteria of factor loading > 0.40 and statistical significance $p <$

0.05. This validation process followed best practices recommended by (Compan et al., 2025) to address the methodological weaknesses often found in sustainability literacy assessment instruments. The instrument's reliability was evaluated using Cronbach's alpha, which yielded a coefficient of $\alpha = 0.959$. This value far exceeds the minimum threshold of 0.70 for social research and is categorized as excellent reliability. This high reliability indicates excellent internal consistency among the instrument's items and strengthens confidence in the measurement results.

Data Collection Procedures

Data collection was conducted online using a validated digital survey platform. Participants received complete information about the study's purpose, procedures, and their rights as respondents. Informed consent was obtained from all participants before accessing the instrument. The survey was designed to be completed within 20–30 minutes to minimize respondent fatigue, following guidelines from the STARS 3.0 framework for sustainability literacy assessment. Data were collected over a two-week period to ensure an optimal response rate (Amprazis & Papadopoulou, 2025).

Data Analyze

Data analysis was conducted using Microsoft Excel to identify the distribution of students across four stages of sustainability literacy. Descriptive analysis was used to calculate the frequency and percentage of students at each scale. Distributional analysis was conducted to identify bimodal or multimodal patterns in the data. Additionally, comparative analysis was conducted to explore differences in distribution based on participants' demographic and academic characteristics. Interpretation of the results was conducted by referring to recent theoretical and empirical literature to identify the pedagogical implications of the findings, including research from transformative learning theory. (Noroozi et al., 2020) 2023) and *experiential learning frameworks* (Chatpinyakoop et al., 2022)

Results

Validity and Reliability of Instruments

Psychometric analysis of the Learning for Sustainability Assessment instrument demonstrated very satisfactory results. Of the 50 items tested, 47 (94%) met validity criteria with factor loadings above 0.40 and statistical significance of $p < 0.05$. Three items that did not meet validity criteria were excluded from further analysis. Valid items were evenly distributed across the four progressive scales, with each scale having at least 10 valid items. These validation results exceeded recommended standards, indicating that many sustainability literacy instruments lack adequate validation.

The instrument's reliability, measured using Cronbach's alpha, reached $\alpha = 0.959$. This value indicates excellent internal consistency and strengthens confidence in the measurement results. Reliability analysis for each subscale also showed high values: Scale 1-Non-Awareness ($\alpha = 0.87$), Scale 2-Awareness ($\alpha = 0.91$), Scale 3-Responsibility ($\alpha = 0.89$), and Scale 4-Leadership ($\alpha = 0.93$). These results confirm that the instrument can measure sustainability literacy with high accuracy and consistency, in line with the rigorous assessment standards emphasized by the Higher Education Sustainability Initiative (Leiva-Brondo et al., 2022).

Distribution of Sustainability Literacy Levels

An analysis of the distribution of sustainability literacy levels among 50 participating students revealed an interesting and unexpected bimodal pattern. The data showed the highest concentration at two extremes: Scale 2—Awareness (38%) and Scale 4—Leadership (40%). This finding indicates that the majority of students fall at two opposite poles of the sustainability literacy spectrum, with nearly equal proportions. This distribution pattern aligns with recent studies showing that the development of sustainability literacy does not always follow a linear progression but can involve transformative leaps (Dedoussi, 2021)

The proportion of students on Scale 3—Responsibility—was relatively low, at only 20% of the total participants. More surprisingly, only 2% of students were identified as being on Scale 1—Non-Awareness. This distribution creates a U-shaped or bimodal pattern indicating a significant gap in the Responsibility stage, which serves as a transitional phase between awareness and leadership. This phenomenon is consistent with the attitude-behavior gap identified in the sustainability education literature (Chen et al., 2022), where students demonstrate a high level of

awareness of sustainability issues but struggle to translate that awareness into a sense of responsibility and concrete action. Table 1 presents the complete distribution of students across the four sustainability literacy scales

Table 1. Pre-Analysis of Student Distribution across Four Scales of Sustainability Literacy

Skala Literasi	Number of Students	Percentage (%)
Scale 1: Non Awareness	1	2%
Scale 2: Awareness	19	38%
Scale 3: Responsibility	10	20%
Scale 4: Leadership Role	20	40%
Total	50	100%

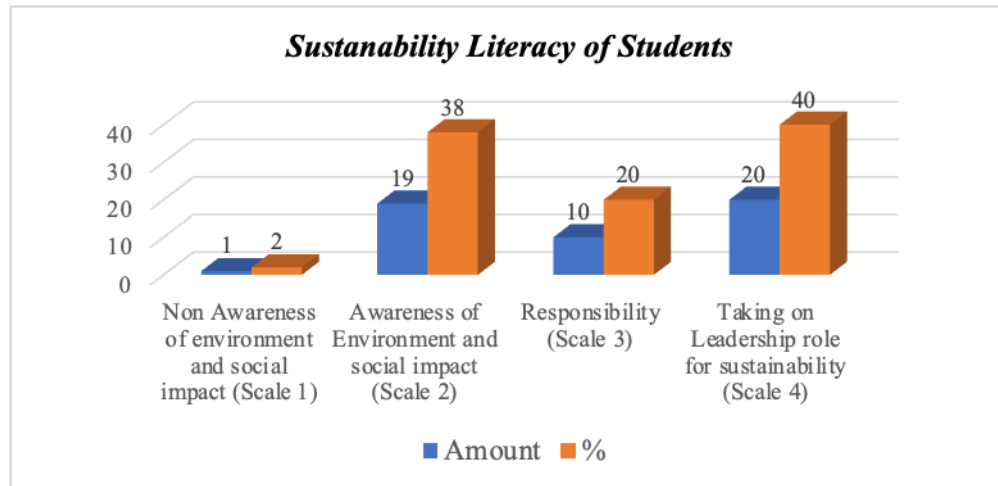


Figure 1. Pre-Analysis of Students' Sustainability Literacy

This bimodal distribution pattern reveals a phenomenon that differs from the assumption of linear progression in sustainability learning. Instead of a normal distribution concentrated in the middle of the spectrum, the data shows a polarization between students at the awareness stage and those who have reached the leadership stage. The gap in the Responsibility stage is a key finding that requires further investigation and specific pedagogical interventions, in line with the transformative learning framework developed by (Ottesen et al., 2023) and (Compan et al., 2025).

Characteristics of Each Scale

Analysis of student characteristics across each scale provides in-depth insights into sustainability literacy profiles. Students on Scale 1—Non-Awareness (2%) demonstrated a very limited understanding of sustainability issues and had not yet recognized the relevance of sustainability to their lives. This very low proportion indicates that the institution's sustainability education program has been successful in raising basic awareness among students, consistent with the global trend of mainstreaming sustainability education in higher education. (Ottesen et al., 2023).

Students on Scale 2-Awareness (38%) demonstrated a good understanding of sustainability concepts and were able to identify relevant sustainability issues. They demonstrated systems-thinking competency and anticipatory competency, two of the five key competencies in sustainability (Annelin & Boström, 2022). However, this awareness has not yet translated into a personal commitment to action or change behavior. This group represents students who have achieved conceptual understanding but are still in the contemplation phase without concrete action, a phenomenon identified as 'knowingness' without 'behavior' in the framework (Chen et al., 2022)

Students on Scale 3-Responsibility (20%) demonstrate a critical transition from awareness to action. They have developed normative competency and strategic competency—the ability to identify sustainability values and design strategies to achieve them (Amprazis & Papadopoulou, 2025). This group has begun to integrate sustainability principles into their daily decisions and actions, although perhaps still on an individual scale. The low proportion on this scale indicates that the transition from awareness to responsibility is a challenging threshold and requires more intensive

pedagogical support, particularly through experiential learning approaches that facilitate real-world engagement (Ramadany et al., 2025).

Students on Scale 4-Leadership (40%) demonstrate a high commitment to sustainability and have taken an active role in promoting change. They demonstrate advanced interpersonal competency and the ability to collaborate, communicate, and lead in interdisciplinary and multicultural contexts (Chien & Chien, 2025). This group demonstrated the characteristics of transformative change agents: long-term vision, the ability to inspire and mobilize others, and the skills to design and implement sustainability initiatives. The high proportion of students on this scale is a very positive finding and indicates significant potential for developing sustainability change agents, in line with the goals of the HESI Framework for sustainability leadership development. (Décamps et al., 2017).

Discussion

The Bimodal Distribution Phenomenon and Its Implications

The bimodal distribution identified in this study challenges traditional assumptions about linear progression in sustainability learning. The U-shaped pattern, with a concentration on Scale 2—Awareness and Scale 4—Leadership, indicates that the development of sustainability literacy can involve transformative leaps—transformative leaps that allow students to 'skip' the Responsibility stage and directly reach Leadership. This phenomenon aligns with transformative learning theory, which emphasizes that transformative learning is not always linear but can involve 'disorienting dilemmas' or critical moments that trigger fundamental perspective shifts. *Recent research* (Persano Adorno et al., 2025) identified that transformative learning in sustainability education involves a complex process in which students experience fundamental changes in their worldview. They argued that critical reflection, concrete experience, and the development of agency are key elements that facilitate this transformation. In the context of this research finding, students ranked on Scale 4-Leadership may have experienced powerful transformative experiences—such as participation in sustainability projects, exposure to real-world sustainability challenges, or engagement with sustainability movements—that facilitate a direct leap from awareness to leadership without going through the prolonged phase on the Responsibility scale.

However, the low proportion of students on Scale 3-Responsibility (20%) also indicates that the traditional pathway from awareness to responsibility remains challenging for the majority of students. This is consistent with the 'attitude-behavior gap' extensively documented in the environmental psychology and sustainability education literature. (Chen et al., 2022) In their study of sustainability literacy in China, they found similar patterns, where students demonstrated high levels of sustainability knowledge and positive attitudes but struggled to translate these into concrete behaviors. They identified that barriers such as perceived lack of self-efficacy, structural constraints, and unsupportive social norms contributed to this gap.

Pedagogical Implications: From Framework to Practice

The findings of this study have significant implications for the design and implementation of sustainability education programs in higher education, particularly in the context of the global movement 'from frameworks to practice'. The bimodal distribution indicates the need for a differentiated and adaptive pedagogical approach for students at different stages (Iqbal et al., 2025). For students on Scale 2-Awareness, interventions should focus on facilitating the transition to Scale 3-Responsibility through experiential learning approaches that have been extensively validated in recent research. In the study (Hajj-Hassan et al., 2024) about *experiential learning for sustainability in engineering education* identified four critical principles for more effective implementation: contextual learning (grounding in real-world contexts), constructive learning (active knowledge construction), collaborative learning (interdisciplinary collaboration), and transformative learning (perspective transformation). They found that approaches such as problem-based learning, project-based learning, and challenge-based learning were highly effective in developing not only cognitive but also affective and social-emotional dimensions, which are important for responsible development.

According (Monika, 2024), provide important insights into the role of formal, informal, and non-formal learning experiences in the development of sustainability competencies. They argue that a hybrid approach that integrates structured learning with informal learning opportunities such as sustainability clubs, volunteering, and community engagement, as well as non-formal experiences such as internships, field trips, and participatory action research, can facilitate the development of a

more comprehensive sustainability literacy. This hybrid approach is particularly relevant for bridging the gap between awareness and responsibility because it provides multiple pathways and touchpoints for students to develop their sense of personal responsibility and agency.

For students on Scale 4—Leadership, the pedagogical focus needs to shift toward developing advanced competencies, including transformative leadership, facilitating systems change, and sustainability innovation. This group of students can function as peer educators, mentors, and change agents within the sustainability education ecosystem. Research findings indicate that peer learning and mentoring programs are highly effective in facilitating sustainability learning, particularly in developing interpersonal competencies and collaborative problem-solving skills. (Bonilla-Jurado et al., 2024; Qadar et al., 2022). Creating structured opportunities for leadership students to mentor awareness students can yield mutual benefits—leadership students develop teaching and facilitation skills, while awareness students gain personalized support and role models who can inspire their transformation process.

Integrating Sustainability Competencies Framework

The complexity of contemporary sustainability challenges necessitates the integration of a comprehensive competency framework with multidimensional coverage. GreenComp: The European Sustainability Competence Framework (Science & Policy, 2022) offers a useful structure through an emphasis on four key competency areas: (1) embodying sustainability values, (2) embracing complexity in sustainability, (3) visualizing sustainable futures, and (4) acting for sustainability. This framework aligns with widely used key competency models that encompass systems thinking, anticipatory, normative, strategic, and interpersonal competencies, but places significant additional emphasis on the values and action-orientation dimensions.

Recent work (Amprazis & Papadopoulou, 2025) demonstrate how the competency framework can be operationalized in specific educational contexts. Their findings indicate that effective integration requires well-trained educators with relevant knowledge, appropriate instructional design, and potential structural changes within educational institutions. A crucial aspect is developing educator competencies in facilitating transformative learning, managing uncertainty and complexity, and supporting students in developing their sustainable agency. (Syofyan & Rachmadtullah, 2019; Vare et al., 2019).

The urgency of a whole-institution approach is an initiative that integrates sustainability competency development across the curriculum, not just isolated courses. It also embeds it in the institutional culture and supports it through organizational practices. This systemic approach recognizes that sustainability education is not solely about individual student learning but encompasses a comprehensive transformation of the educational ecosystem to support the transition to sustainability.

Limitations and Recommendations for Future Research

While this study provides valuable insights into the distribution of sustainability literacy, several limitations should be acknowledged. First, the relatively small sample size (n=50) limits the generalizability of the findings. Further research with larger, more representative samples is needed to confirm the identified bimodal distribution pattern. (Annelin & Boström, 2022) In their systematic review, they recommended minimum sample sizes and rigorous validation procedures for sustainability literacy assessment instruments.

Second, the cross-sectional design used in this study does not facilitate analysis of students' transitions between scales over time. Longitudinal studies are essential to understand the dynamics of literacy development and identify factors that facilitate or hinder learning progression. Recommended research designs could include repeated assessments across academic years combined with qualitative methods to capture transformative experiences and critical incidents that trigger transitions between scales.

Third, the use of self-report instruments is susceptible to social desirability bias. Future research could integrate multiple assessment methods, including behavioral observation, performance-based assessment, and portfolio evaluation, to provide a more comprehensive picture of students' sustainability literacy. The approach applied combines literacy assessment with cultural and behavioral assessments, providing a useful model for multi-method assessment. (Noroozi et al., 2020). Fourth, this research has not fully explored contextual factors that potentially influence literacy distribution, such as specific pedagogical interventions, curricular design, institutional support, and cultural context. Future research needs to systematically investigate these factors to

identify best practices and transferable principles in sustainability education. Comparative studies across different institutions, cultural contexts, and disciplinary backgrounds can provide valuable insights into effective interventions, the contexts in which they are implemented, and the reasons for their success.

Conclusion

This study revealed a unique bimodal distribution pattern in students' sustainability literacy, with the highest concentrations at the Awareness (38%) and Leadership (40%) stages, while only 20% were at the Responsibility stage and 2% at the Non-Awareness stage. This finding challenges the assumption of linear progression in sustainability learning and indicates a significant gap in the transition from awareness to responsibility. Excellent instrument validity (94% valid items) and high reliability ($\alpha = 0.959$) strengthen confidence in the study's findings. The gap at the Responsibility stage indicates the need for reformulating pedagogical strategies that specifically target the transition from awareness to action through an experiential learning approach.

The study recommends five key strategies: (1) developing experiential learning programs that facilitate authentic engagement with sustainability challenges; (2) creating a peer mentoring system; (3) integrating formal, informal, and non-formal learning experiences; (4) adopting a whole-institution approach that embeds sustainability into the institutional culture; and (5) conducting regular sustainability literacy assessments. The high proportion of students at the Leadership stage represents a valuable asset that can be leveraged to strengthen the sustainability education ecosystem. However, addressing the accountability gap remains a critical priority, requiring systematic implementation strategies, adequate institutional support, and ongoing evaluation.

A key implication of this research is the urgency of developing adaptive and differentiated pedagogical strategies tailored to students' literacy stages. Future research should prioritize longitudinal studies to understand the dynamics of literacy development over time and explore contextual factors that influence the progression of sustainability learning.

Acknowledgements

This research was supported by the Research Fund of the Ministry of Education and Technology and the Research and Community Service Institute (LPPM) of Esa Unggul University. The authors would like to thank all the students who participated in this research and the panel of experts who provided valuable input in the instrument validation process. The authors also thank the reviewers who provided constructive suggestions to improve the quality of this article.

References

- Amprazis, A., & Papadopoulou, P. (2025). Key competencies in education for sustainable development: A valuable framework for enhancing plant awareness. *Plants People Planet*, 7(4), 1195–1211. <https://doi.org/10.1002/ppp3.10625>
- Annelin, A., & Boström, G. O. (2022). An assessment of key sustainability competencies: a review of scales and propositions for validation. *International Journal of Sustainability in Higher Education*, 24(9), 53–69. <https://doi.org/10.1108/IJSHE-05-2022-0166>
- Bitar, N., & Davidovitch, N. (2024). Cultural Adaptation of Digital Learning Tools in Israeli Higher Education: A Case Study of Lecturer Perceptions and Practices. *TechTrends*, 68(6), 1152–1165. <https://doi.org/10.1007/s11528-024-01007-3>
- Bonilla-Jurado, D., Zumba, E., Lucio-Quintana, A., Yerbabuena-Torres, C., Ramírez-Casco, A., & Guevara, C. (2024). Advancing University Education: Exploring the Benefits of Education for Sustainable Development. *Sustainability*, 16(17), 7847. <https://doi.org/10.3390/su16177847>
- Chatpinyakoo, C., Hallinger, P., & Showanasai, P. (2022). Developing Capacities to Lead Change for Sustainability: A Quasi-Experimental Study of Simulation-Based Learning. *Sustainability (Switzerland)*, 14(17). <https://doi.org/10.3390/su141710563>
- Chen, C., An, Q., Zheng, L., & Guan, C. (2022). Sustainability Literacy: Assessment of Knowingness, Attitude and Behavior Regarding Sustainable Development among Students in China. *Sustainability (Switzerland)*, 14(9). <https://doi.org/10.3390/su14094886>
- Chien, C. T., & Chien, C. H. (2025). Evaluating Problem-Based Learning in an ESG-Centered General Education Course: A Mixed-Methods Study of Student Competency Development. *Sustainability (Switzerland)*, 17(17). <https://doi.org/10.3390/su17177944>
- Compan, P., Prommachan, T., Kongyok, C., Cheablam, O., & Socheath, M. (2025). Integrating Local Plant Knowledge into Elementary Curriculum: A Scalable Model for Community

- Sustainability. *Sustainability* (Switzerland), 17(17), 1–25. <https://doi.org/10.3390/su17178060>
- Décamps, A., Barbat, G., Carteron, J. C., Hands, V., & Parkes, C. (2017). Sulitest: A collaborative initiative to support and assess sustainability literacy in higher education. *International Journal of Management Education*, 15(2), 138–152. <https://doi.org/10.1016/j.ijme.2017.02.006>
- Dedoussi, I. C. (2021). Implications of future atmospheric composition in decision-making for sustainable aviation. *Environmental Research Letters*, 16(3). <https://doi.org/10.1088/1748-9326/abe74d>
- Diamond, S., & Irwin, B. (2013). Using e-learning for student sustainability literacy: Framework and review. *International Journal of Sustainability in Higher Education*, 14(4), 338–348. <https://doi.org/10.1108/IJSHE-09-2011-0060>
- Ekawati, D., Surya Adnyani, N. L., Sintya Wahyu Widyantari, N. P., & Susiani, K. (2025). Mengintegrasikan perspektif SDGs (tujuan pembangunan berkelanjutan) dalam pembelajaran ilmu pengetahuan sosial untuk membangun kepedulian dan rasa tanggung jawab sosial. *JPGI (Jurnal Penelitian Guru Indonesia)*, 10(1), 56–61. <https://doi.org/10.29210/025727jpgi0005>
- Hajj-Hassan, M., Chaker, R., & Cederqvist, A. M. (2024). Environmental Education: A Systematic Review on the Use of Digital Tools for Fostering Sustainability Awareness. *Sustainability (Switzerland)*, 16(9), 1–25. <https://doi.org/10.3390/su16093733>
- Idoiaga, Mondragon, N., Yarritu, I., Saez de Cámara, E., Beloki, N., & Vozmediano, L. (2023). The challenge of education for sustainability in higher education: key themes and competences within the University of the Basque Country. *Frontiers in Psychology*, 14(July), 1–12. <https://doi.org/10.3389/fpsyg.2023.1158636>
- Iqbal, J., Hashmi, Z. F., Seitamaa-Hakkarainen, P., & Asghar, M. Z. (2025). Exploring perceived sustainable competencies in relation to curricula, generative AI tool usage, and knowledge sharing in blended learning. *Scientific Reports*, 15(1), 35651. <https://doi.org/10.1038/s41598-025-19625-z>
- Kuehl, C., Sparks, A. C., Hodges, H., & Smith, E. R. A. N. (2023). Exploring sustainability literacy: developing and assessing a bottom-up measure of what students know about sustainability. *Frontiers in Sustainability*, 4. <https://doi.org/10.3389/frsus.2023.1167041>
- Leal, S., Nascimento, J., Piki, A., Tekerek, A., Güzel, A., Loureiro, A., Gonçalves, C., Messias, I., Simons, J., Teunen, L., Barradas, L. C. S., Palmer, N., Mongelli, T. L., Nedelko, Z., & Oliveira, S. (2024). Exploring sustainable development perceptions among higher education students: An empirical study on knowledge, attitudes, and behaviours. *Cleaner and Responsible Consumption*, 14(September). <https://doi.org/10.1016/j.clrc.2024.100223>
- Leiva-Brondo, M., Lajara-Camilleri, N., Vidal-Meló, A., Atarés, A., & Lull, C. (2022). Spanish University Students' Awareness and Perception of Sustainable Development Goals and Sustainability Literacy. *Sustainability (Switzerland)*, 14(8), 1–26. <https://doi.org/10.3390/su14084552>
- Lozano, R., Barreiro-Gen, M., D'Amato, D., Gago-Cortes, C., Favi, C., Martins, R., Monus, F., Caeiro, S., Benayas, J., Caldera, S., Bostanci, S., Djekic, I., Moneva, J. M., Sáenz, O., Awuzie, B., & Gladysz, B. (2023). Improving sustainability teaching by grouping and interrelating pedagogical approaches and sustainability competences: Evidence from 15 Worldwide Higher Education Institutions. *Sustainable Development*, 31(1), 349–359. <https://doi.org/10.1002/sd.2396>
- Martin, M., Stadler, M., Künsting, J., Schwichow, M., Asshoff, R., Bender, U., Birke, F., Carrapatoso, A., Grundmeier, A. M., Höger, C., Schuler, S., Stemann, J., & Rieß, W. (2025). Assessing climate literacy in secondary schools: development and validation of an interdisciplinary competence test. *Frontiers in Education*, 10. <https://doi.org/10.3389/educ.2025.1637522>
- Maulana, S., Rusilowati, A., Nugroho, S. E., & Susilaningih, E. (2024). Designing Test Software for Pre-Learning Evaluation to Optimize the Differentiated Learning. *TEM Journal*, 13(3), 2483–2492. <https://doi.org/10.18421/TEM133-74>
- Miterianifa, M., & Mawarni, M. F. (2024). Penerapan Model Pembelajaran Literasi Lingkungan dalam Meningkatkan Pengetahuan dan Kesadaran Lingkungan. *Jurnal Sains Dan Edukasi Sains*, 7(1), 68–73. <https://doi.org/10.24246/juses.v7i1p68-73>
- Monika, J. (2024). *Sustainability Education in the 21st Century: Incorporating Environmental Awareness in K-12 Curriculum*. 2(3), 120–133.

- Mróz, A., & Ocetkiewicz, I. (2024). Anticipatory Thinking as a Key Competence in Management for Sustainability: The Results of Research Among Polish Teenagers. *Sustainability (Switzerland)*, 16(22), 1–17. <https://doi.org/10.3390/su162210036>
- Mulyadiprana, A., Yulianto, A., Hamdu, G., & Putri, A. R. (2022). Rancang Bangun Kegiatan Pengenalan Green Behavior: Penerapan Program ESD di Sekolah Dasar. *Edukatif: Jurnal Ilmu Pendidikan*, 4(2), 2370–2377. <https://doi.org/10.31004/edukatif.v4i2.2344>
- Noroozi, O., Pijera-Díaz, H. J., Sobocinski, M., Dindar, M., Järvelä, S., & Kirschner, P. A. (2020). Multimodal data indicators for capturing cognitive, motivational, and emotional learning processes: A systematic literature review. In *Education and Information Technologies* (Vol. 25, Issue 6). <https://doi.org/10.1007/s10639-020-10229-w>
- Nugraha, N., Lhutfi, I., Tanuatmodjo, H., & Triansyah, F. A. (2023). Institutional Sustainability Development of Higher Education in Indonesia. *Dinamika Pendidikan*, 18(1), 53–65. <https://doi.org/10.15294/dp.v18i1.43814>
- Ottesen, A., Thom, D., Bhagat, R., & Mourdaa, R. (2023). Learning from the Future of Kuwait: Scenarios as a Learning Tool to Build Consensus for Actions Needed to Realize Vision 2035. *Sustainability (Switzerland)*, 15(9). <https://doi.org/10.3390/su15097054>
- Persano Adorno, D., Birsan, E. A., Stoica, S. F., Capatina, M., Cojocaru, C., Tzortzaki, A., Ștanfelj, Z., Dinçer, Y. S., & Pizzolato, N. (2025). Sustainability as a Cross-Curricular Link: Creative European Strategies for Eco-Conscious Environmental Education. *Sustainability (Switzerland)*, 17(11), 1–16. <https://doi.org/10.3390/su17115193>
- Priyanka, AshuSharma, MuskanTakiar, & JasleenKaur. (n.d.). *View of Constructivist Approaches to Teaching_ Promoting Sustainability and Critical Thinking among Students.pdf*.
- Qadar, R., Haryanto, Z., Subagiyo, L., Junus, M., & Syam, M. (2022). Indonesian Science Teachers' Ability to Design Scientific Literacy Test. *International Journal of STEM Education for Sustainability*, 2(1), 133–139. <https://doi.org/10.53889/ijses.v2i1.52>
- Ramadany, L. D., Sujana, A., Sopandi, W., & Hidayat, F. A. (2025). Profiling Sustainable Environmental Awareness of Primary School Students in Sorong District by Gender and School Location. *Journal of Science Education Research*, 9(2), 106–113. <https://doi.org/10.21831/jser.v9i2.80466>
- Ramadhani, A. M., & Sunarya, Y. (2024). Meninjau Konsep Green Education dalam Penelitian Pengajaran Sastra dan Kaitannya dengan Profil Pelajar Pancasila. *Edukatif: Jurnal Ilmu Pendidikan*, 6(4), 3734–3744. <https://doi.org/10.31004/edukatif.v6i4.6806>
- Redman, A., Wiek, A., & Barth, M. (2021). Current practice of assessing students' sustainability competencies: a review of tools. *Sustainability Science*, 16(1), 117–135. <https://doi.org/10.1007/s11625-020-00855-1>
- Saifana Iluj' Dhia Hakiki, & Diki Anggi Saputra. (2024). Effectiveness of Environmental Education Programs for College Students in Enhancing Sustainability Education for SDG's 2030 : A Systematic Literature Review. *Proceeding of The International Conference of Inovation, Science, Technology, Education, Children, and Health*, 4(2), 156–171. <https://doi.org/10.62951/icistech.v4i2.98>
- Santiani, S., Rusilowati, A., Sudarmin, S., & Ngabekti, S. (2023). Fit-Model Sustainable Competencies of Palangka Raya Indonesia Peat Lands in the Environmental Literacy (P-PSEL) Questionnaire for Teacher-Candidates. *Polish Journal of Environmental Studies*, 32(2), 1781–1788. <https://doi.org/10.15244/pjoes/157496>
- Science, J. R. C., & Policy, F. O. R. (2022). *GreenComp The European sustainability competence framework*. <https://doi.org/10.2760/13286>
- Syofyan, H., & Rachmadtullah, R. (2019). Increasing Ecoliteracy on the Impact of Organic Waste Management Using a Problem a Problem-solving the Model. *International Journal of Scientific and Technology Research*.
- Uzorka, A., Akiyode, O., & Isa, S. M. (2024). Strategies for engaging students in sustainability initiatives and fostering a sense of ownership and responsibility towards sustainable development. *Discover Sustainability*, 5(1). <https://doi.org/10.1007/s43621-024-00505-x>
- Vare, P., Arro, G., de Hamer, A., Gobbo, G. Del, de Vries, G., Farioli, F., Kadji-Beltran, C., Kangur, M., Mayer, M., Millican, R., Nijdam, C., Réti, M., & Zachariou, A. (2019). Devising a competence-based training program for educators of sustainable development: Lessons learned. *Sustainability (Switzerland)*, 11(7), 1–21. <https://doi.org/10.3390/su11071890>
- Widiyastuti, D. A., Nurtamara, L., & Ulimaz, A. (2024). Analisis Kesadaran Dan Literasi Lingkungan Pada Mahasiswa Pendidikan Biologi. *Journal on Education*, 6(4), 18987–18997.

<https://doi.org/10.31004/joe.v6i4.5880>

- Yanti, F. A., Wardana, R. W., Buyung, B., Heryensi, E., & Khamis, N. (2025). Automatic Assessment- Based Artificial Intellegent to Measure Students Environmental Literacy. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, 7(3), 461–480. <https://doi.org/10.23917/ijolae.v7i3.11240>
- Zulfah, N. L. N., Purnamasari, S., & Abdurrahman, D. (2024). JKPI : Jurnal Kajian Pendidikan IPA sustainable development (ESD) terhadap literasi lingkungan siswa pada. *JKPI: Jurnal Kajian Pendidikan IPA*, 4(1), 299–304.