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Personalized Sustainability Education in the Digital Age: Effects on Learner Engagement and Environmental Awareness to Support Sustainable Development Goals (SDGs)

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ABSTRACT

This study explores the role of personalized sustainability education (PSE) in promoting learner engagement (LE) and environmental awareness (EA) among elementary school students in Indonesia. Using a quantitative cross-sectional design, data were collected from 114 fifth-grade students across four provinces through validated instruments. Structural Equation Modeling (PLS-SEM) was applied to examine the hypothesized relationships. The results show that PSE has a significant positive effect on both LE and EA, while LE also positively influences EA. Furthermore, PSE mediates the relationship between LE and EA, suggesting that personalization strengthens the translation of engagement into awareness. By making learning experiences more meaningful and contextually relevant, PSE enhances students' understanding and commitment to sustainability practices. Theoretically, this study advances research on personalized learning and Education for Sustainable Development (ESD). Practically, it highlights the potential of digital personalization strategies to increase engagement, foster awareness, and cultivate pro-environmental behaviors from an early age.

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1. INTRODUCTION

Education in the 21st century faces the dual challenge of not only developing students' academic competencies but also cultivating awareness, attitudes, and behaviors that support sustainable living. Within this framework, learner engagement (LE) and environmental awareness (EA) are two interrelated components that are essential for future-oriented education. Learner engagement (commonly defined as students' behavioral, emotional, and cognitive involvement) is a key indicator of successful learning (Fredricks *et al*., 2004). Its behavioral dimension reflects students' active participation in learning activities; the emotional dimension involves interest, belonging, and attachment to learning; while the cognitive dimension refers to the mental effort invested in processing and understanding information. High levels of engagement are consistently associated with improved academic achievement, intrinsic motivation, and sustained lifelong learning. In parallel, environmental awareness—within the framework of Education for Sustainable Development (ESD)—is understood as knowledge of human–environment relationships, positive attitudes toward conservation, and the skills needed for action. It is critical in preparing younger generations to confront challenges such as climate change, environmental degradation, and resource scarcity (Susilawati *et al*., 2025). High levels of awareness require not only an understanding of ecological issues but also the acquisition of key ESD competencies such as systems thinking, critical thinking, collaboration, and action orientation (Wardani *et al*., 2021). Ideally, strong engagement contributes to the growth of environmental awareness, which in turn motivates students to adopt pro-environmental behaviors in daily life.

However, research highlights a significant gap between this ideal and classroom realities. The widely documented knowledge–action gap demonstrates that knowledge and positive attitudes do not automatically translate into consistent pro-environmental behaviors (Kollmuss & Agyeman, 2002). This gap may arise from low self-efficacy, lack of supportive environments, or limited opportunities for action (Bamberg & Möser, 2007). Moreover, although environmental education often enhances knowledge, attitudes, and even pro-environmental intentions among youth, its effectiveness depends heavily on pedagogical design, contextual relevance, and sustained implementation. Many programs remain limited to information delivery, which hinders value internalization and habit formation. A further challenge lies in uniform, one-size-fits-all approaches where content, methods, and assessments are applied equally to all students, without accounting for differences in interests, learning styles, or ability levels. Differentiated instruction improves achievement only when personalization is consistent, data-driven, and contextually relevant. Within environmental education, insufficient differentiation can lower engagement, especially when students find content too difficult, too easy, or irrelevant to their lives.

Preliminary evidence from elementary schools supports these findings. First, students demonstrate heterogeneous levels of knowledge and interest in environmental topics (Jarrett & Takacs, 2020). Some show enthusiasm and understanding, while others express limited interest or misconceptions. Second, learning materials are often not sequenced according to students' abilities (Mohan *et al*., 2008), making it difficult for teachers to provide targeted instruction. Third, formative and summative assessments rarely include actionable feedback, leaving students uncertain about how to improve (Meyer *et al*., 2019). Fourth, students tend to focus on familiar content while avoiding challenging topics, leading to repetitive learning and limited competency development (Subban, 2006).

The rise of digital technologies offers opportunities to address these challenges through personalized learning. This approach adapts content, pathways, and assessments to student profiles (such as prior knowledge, learning preferences, and performance history). Learning Recommender Systems (LRS) exemplify such technologies, recommending relevant materials, activities, or resources (Wetering *et al*., 2015; Verbert *et al*., 2012). Tailoring content to students' interests can enhance engagement and performance, provided instructional design and cognitive load are well managed (Walkington, 2013). In ESD, adaptive recommender systems hold promise for bridging the knowledge-action gap. By integrating formative assessments, interaction data, and content preferences, these systems can generate tailored recommendations that are both relevant and appropriately challenging. For example, students with limited knowledge of recycling may receive interactive simulations, while those with advanced understanding may be directed toward real-life projects at school or home. In this way, personalization supports behavioral, emotional, and cognitive engagement while deepening environmental awareness and fostering lasting pro-environmental behavior.

The novelty of this study lies in three main contributions. First, this study empirically examines the impact of data-driven adaptive recommender systems on learner engagement (LE) and environmental awareness (EA) at the elementary school level—an area that remains largely underexplored in existing research. Second, it integrates personalized learning principles with sustainability education within a digital pedagogical framework, offering a systematic approach to bridging the long-standing knowledge–action gap in environmental education. Third, it provides practical insights into the design and implementation of adaptive and contextually relevant learning interventions that enhance engagement and foster actionable awareness among young learners. Thus, this study contributes both theoretically, by advancing the integration of personalized learning and Education for Sustainable Development (ESD), and practically, by demonstrating how educational technology can be leveraged to cultivate pro-environmental behavior from an early age.

Thus, the objective of this study is to examine the role of personalized sustainability education (PSE) in enhancing LE and EA among elementary students in Indonesia. To achieve this, a quantitative cross-sectional design was employed, with Structural Equation Modeling (PLS-SEM) used to test hypothesized relationships between PSE, LE, and EA. By combining empirical analysis with a robust methodological framework, this study aims to generate evidence-based recommendations for integrating adaptive, personalized, and sustainability-focused strategies into primary education.

2. LITERATURE REVIEW

2.1. Personalization in Digital Education and Learner Engagement

The rapid growth of digital technologies has transformed educational practices by enabling highly adaptive and personalized learning environments. In digital education, personalization refers to tailoring learning content, pace, and delivery to match learners' needs, preferences, and prior knowledge. Within the scope of this study, personalization is conceptualized as an adaptive recommendation system that delivers sustainability-related content, aligning technological innovation with the pedagogical goal of fostering sustainable competencies. Research consistently shows that personalized learning environments enhance intrinsic motivation and strengthen learner engagement by making learning experiences more relevant and meaningful (Ma *et al*., 2014). Learner engagement—commonly defined as a multidimensional construct encompassing behavioral, emotional, and cognitive dimensions—is widely recognized as a strong predictor of academic success and deep learning (Fredricks *et* al., 2004). In the context of sustainability education, engagement is especially critical, as sustainability issues are inherently complex and require critical reflection, active participation, and emotional commitment to develop a genuine understanding.

Empirical evidence further supports this link. For example, students in personalized digital learning environments demonstrate greater persistence, self-regulation, and active participation compared to those in traditional settings (Bernacki & Walkington, 2018). Accordingly, this study posits that personalized digital education positively influences learner engagement. **Figure 1** illustrates the hypothesized relationship between personalized digital education, adaptive recommendation systems, and sustainability-focused content in fostering learner engagement. The model illustrates how adaptive recommendation systems that deliver sustainability-related content can enhance the behavioral, emotional, and cognitive dimensions of learner engagement, leading to the following hypothesis: *"Hypothesis 1 (H1). Personalized digital education has a positive effect on learner engagement".*

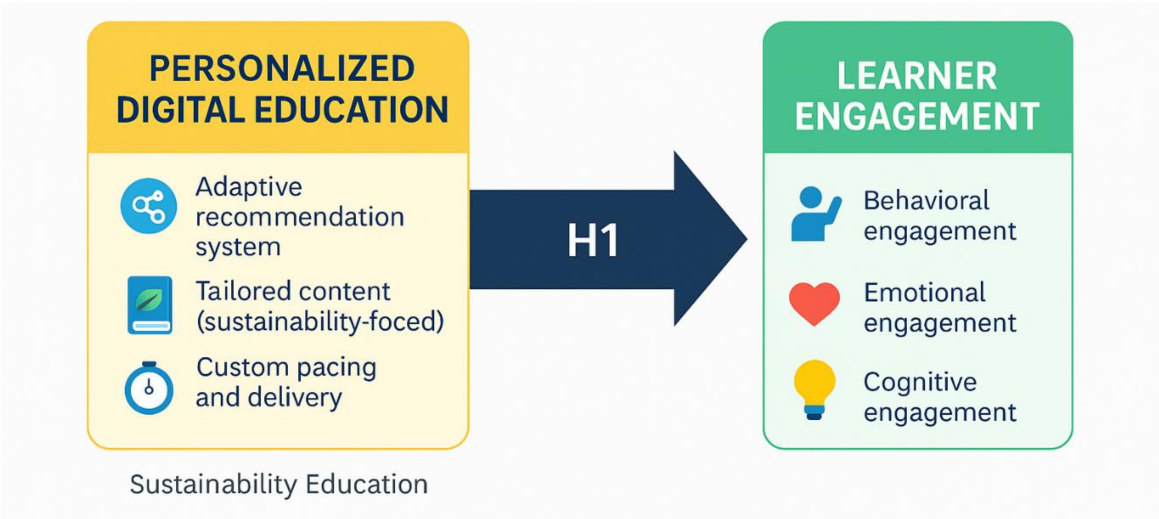

Figure 1. Conceptual framework illustrating the influence of Personalized Digital Education (PDE) on Learner Engagement (LE).

2.2. Personalization in Sustainability Education and Environmental Awareness

Sustainability education aims to cultivate knowledge, attitudes, and behaviors that support sustainable development and environmental protection. Education for Sustainable Development (ESD) is essential for equipping learners with the knowledge, critical thinking skills, and sense of responsibility required to address complex sustainability challenges (Wiek *et al*., 2011). Within this framework, personalized approaches hold particular promise, as tailoring content to learners' contexts, interests, and experiences enhances both relevance and impact.

Empirical evidence supports this perspective. Sustainability-focused courses integrating interactive, problem-based, and context-sensitive strategies were more effective in raising students' environmental awareness than traditional curricula (Lozano et al., 2017). Similarly, sustainability education is most impactful when global environmental issues are meaningfully connected to learners' personal and local experiences, thereby fostering deeper responsibility and awareness (Wals, 2012).

Taken together, these findings suggest that personalized sustainability education (PSE) can serve as a powerful driver of environmental awareness. As illustrated in **Figure 2**, PSE enhances environmental awareness by tailoring content to learners' contexts, interests, and experiences, leading to improved knowledge, attitudes, and pro-environmental behaviors.

The cycle highlights that sustainability education is most effective when it integrates contextually relevant strategies, interactive and problem-based learning, and aligns with the principles of Education for Sustainable Development (ESD). The arrows indicate the direction of influence, while the circular feedback loop suggests that enhanced environmental awareness (EA) can, in turn, reinforce learner engagement and strengthen personalized learning interventions. This dynamic creates a continuous mechanism for fostering sustainability competencies in students, leading to the following hypothesis: *"Hypothesis 2 (H2). Personalized sustainability education has a positive effect on environmental awareness".*

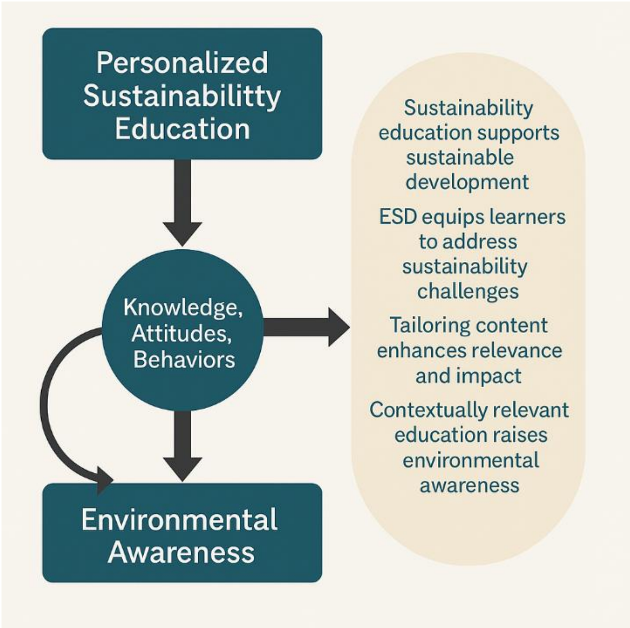

Figure 2. Conceptual framework illustrating the impact of Personalized Sustainability Education (PSE) on Environmental Awareness (EA).

2.3. Learner Engagement and Environmental Awareness

Learner engagement is not only linked to academic performance but also to the internalization of values and awareness that extend beyond cognitive learning outcomes. Engaged learners are more likely to reflect critically, process information deeply, and connect learning content with real-life issues (an essential element of sustainability education). Engagement, through its behavioral, emotional, and cognitive dimensions, enhances learners' ability to integrate new knowledge and values into their worldview (Appleton *et al*., 2008).

Research in sustainability contexts further supports this connection. Students who actively participated in sustainability-related programs demonstrated significantly higher levels of ecological awareness and pro-environmental attitudes (Higgins *et al*., 2008). From a constructivist perspective, meaningful learning occurs when students actively construct knowledge rather than passively receive it (Chi & Wylie, 2014). In this sense, learner engagement acts as a catalyst for translating sustainability education into environmental awareness.

As illustrated in **Figure 3**, learner engagement (across its behavioral, emotional, and cognitive dimensions) positively influences environmental awareness by fostering deep processing, critical reflection, and meaningful connections between learning content and real-life sustainability issues. Engaged learners are thus more likely to internalize knowledge, develop pro-environmental attitudes, and adopt sustainable behaviors. The arrow indicates the hypothesized direction of influence (H3), suggesting that higher levels of learner engagement lead to enhanced environmental awareness. *"Hypothesis 3 (H3). Learner engagement positively affects environmental awareness"*.

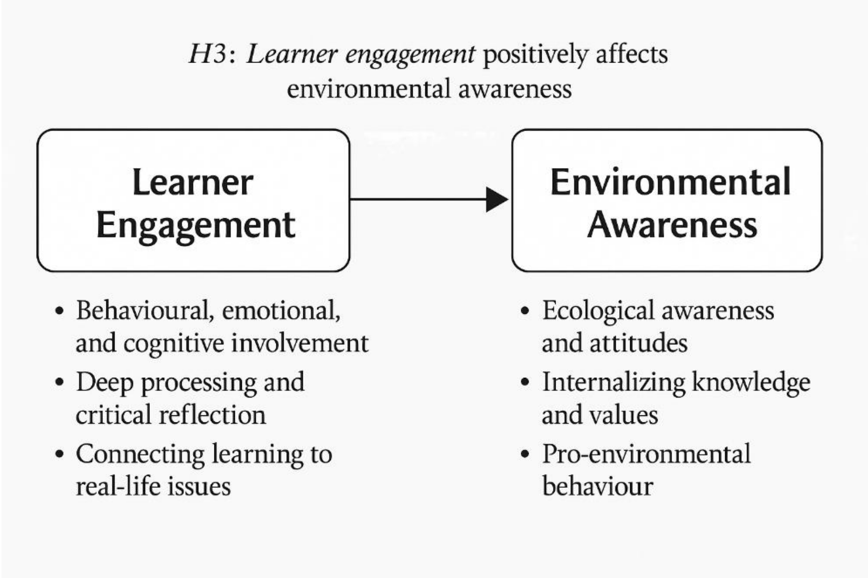

Figure 3. Conceptual framework illustrating the influence of Learner Engagement (LE) on Environmental Awareness (EA).

2.4. The Mediating Role of Personalized Sustainable Education in the Relationship between Learning Engagement and Environmental Awareness

Recent studies suggest that learner engagement plays a critical role in enhancing environmental awareness; however, this relationship is not always direct and is often shaped by context-specific educational interventions, particularly personalized sustainability education (PSE). Personalized sustainability education models—tailored to students' interests, backgrounds, learning styles, and local contexts—enable learners to engage more actively at cognitive, emotional, and behavioral levels, thereby strengthening the connection between engagement and awareness. For instance, research in music education has shown that student engagement mediates the relationship between sustainable music education and environmental awareness, with innovative pedagogical approaches amplifying this effect (Luo & Wang, 2025; Lorenzo de Reizabal, 2022; Jian, 2022; Wnag & Huang, 2024; Massy & Sembiante, 2023). Similarly, literature in Education for Sustainable Development (ESD) emphasizes that environmental attitudes, self-efficacy, and social norms can serve as significant mediators between educational interventions and pro-environmental behavior (Zhang & Chao, 2025).

Building on this evidence, PSE can be hypothesized as an effective mediator that reinforces the influence of learner engagement on environmental awareness through pedagogical and psychological mechanisms that are responsive to learners' individual needs. As illustrated in **Figure 4**, learner engagement (LE) serves as the antecedent variable influencing environmental awareness (EA), with PSE acting as a mediator. By offering tailored content, contextual relevance, and learner-centered approaches, PSE amplifies cognitive, emotional, and behavioral engagement in sustainability education. This, in turn, strengthens the translation of engagement into environmental awareness, providing an indirect pathway through which educational interventions maximize the impact of LE on knowledge, attitudes, and pro-environmental behaviors (Luo & Wang, 2025; Verbert *et al*., 2021). The arrows in the model illustrate the hypothesized relationships, with H4 indicating the mediating effect of PSE.

"Hypothesis 4. Personalized Sustainable Education mediates the relationship between learning engagement and environmental awareness".

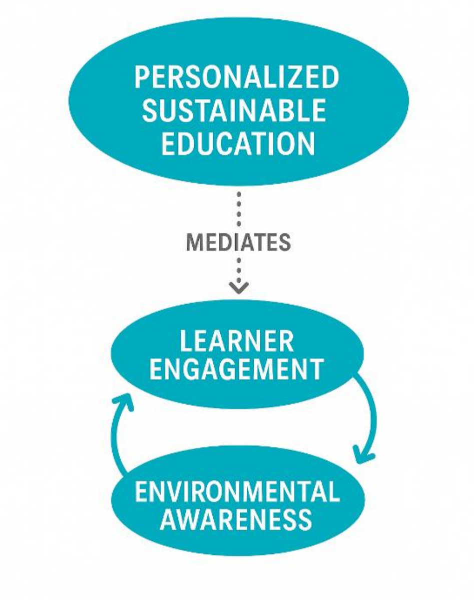

Figure 4. Conceptual framework illustrating the mediating role of Personalized Sustainable Education (PSE) in the relationship between Learner Engagement (LE) and Environmental Awareness (EA).

2.5. The Hypothesis Model

Based on the reviewed literature and the hypotheses derived from the preceding theoretical analysis, a conceptual research framework has been established. As illustrated in **Figure 5**, the proposed framework delineates the structural relationships among the study variables, aligning with the hypothesized model and providing a visual representation of the pathways through which personalized sustainability education, learner engagement, and environmental awareness interact.

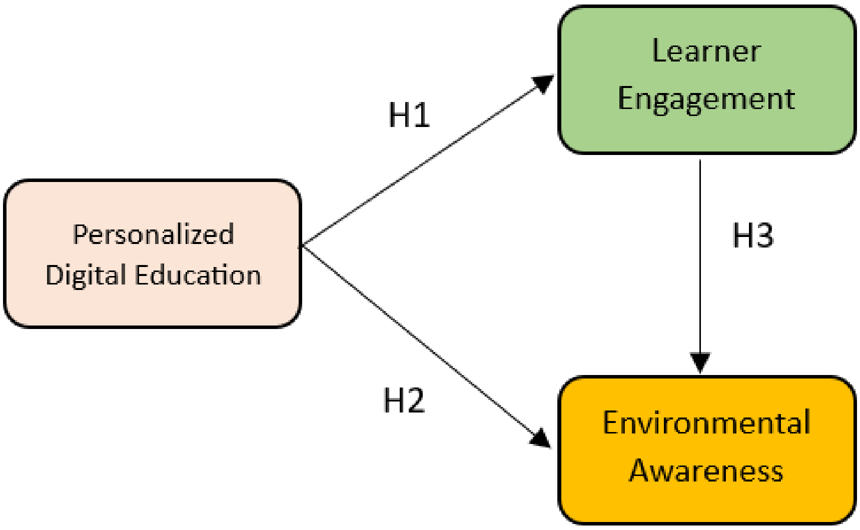

Figure 5. The hypothesized model.

3. METHOD

3.1. Research Design

This study adopts a quantitative research design with a cross-sectional approach (Aboussalah *et al.*, 2022). The primary aim is to examine the effects of personalized sustainability education in the digital era on learner engagement and environmental awareness, as well as to explore the structural relationships among these constructs. A cross-sectional design was selected because it provides efficiency in terms of time and cost compared to longitudinal studies, while still enabling rigorous testing of the hypothesized relationships.

Before data collection, expert validation of the research instruments was carried out to ensure the reliability and validity of the measures used for personalized sustainability education, learner engagement, and environmental awareness. Following instrument validation, the study employed Structural Equation Modeling (SEM) to test the proposed hypotheses. SEM is a robust multivariate statistical technique that allows for the simultaneous estimation and testing of complex relationships among independent and dependent variables, whether latent or observed. It integrates various analytical approaches, including path analysis, causal modeling, confirmatory factor analysis, and covariance structure analysis, making it particularly well-suited for evaluating theoretically grounded models in educational and behavioral research.

3.2. Sampling

The sample for this study consists of elementary school students participating in personalized sustainability education programs delivered through digital platforms. Schools were selected using purposive sampling based on specific criteria to ensure the relevance of the research context. The selection criteria included: (i) schools with reliable internet connectivity and adequate computer facilities to support digital-based personalized learning; (ii) schools that incorporate sustainability education or environmental literacy into their curriculum or extracurricular activities; (iii) schools with teachers trained in digital learning technologies to ensure effective implementation of personalized instruction; and (iv) schools located in both urban and semi-urban areas to capture diverse learning contexts in the digital era. By selecting schools that meet these requirements, the study ensures alignment between the technological infrastructure needed for digital personalization and the pedagogical commitment to sustainability education, thereby strengthening the validity and enhancing the generalizability of the findings.

3.3. Instrument

The research instrument was developed to collect data aligned with the objectives of this study. A structured questionnaire using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), served as the primary tool. This scale was chosen because it enables the systematic measurement of students' perceptions, attitudes, and behavioral tendencies quantitatively. The development of the instrument was informed by an extensive review of the literature and prior studies related to the three main variables: Personalized Sustainability Education, Learner Engagement, and Environmental Awareness. Each item was carefully designed to represent the indicators of the respective constructs, thereby ensuring content validity and consistency with the conceptual framework of the study. To further enhance rigor, the instrument was adapted from established constructs and indicators in previous empirical research, with modifications made to suit the present research context.

Validation was conducted in several stages. First, the questionnaire was assessed for readability by students to ensure clarity and accessibility. Second, two experts—lecturers specializing in sustainability studies and elementary education—reviewed the instrument, and revisions were made based on their feedback. Finally, a pilot test was administered to 102 fifth-grade students across three elementary schools in Bandung under teacher supervision. The results confirmed that all items met the required criteria for validity and reliability. Accordingly, the final questionnaire used in this study consists of 18 items. **Table 1** presents the operational definitions, indicators, and references for each construct, while **Table 2** summarizes the results of the pilot test.

Table 1. Operational definition, questionnaire items, and reference.

Dimension	Operational Definition	Questions	References
Personalized Sustainability Education (PSE)	Digital learning that adapts content, methods, and learning contexts to the needs, interests, and backgrounds of students to enhance their understanding of sustainability issues.	PSE1: The digital learning platform provides sustainability content tailored to my individual learning needs. PSE2: The materials presented are relevant to my personal interests and background. PSE3: The personalized approach in digital learning helps me better understand complex sustainability issues. PSE4: The system adapts the pace and method of teaching according to my progress. PSE5: This learning approach connects global sustainability challenges with my local context. PSE6: Personalized learning motivates me to reflect critically on my role in promoting sustainability.	(Ma *et al*., 2014); Bernacki & Walkington, 2018).
Learner Engagement (LE)	The degree of students' behavioral, cognitive, and emotional engagement in the process of digital learning, particularly within the context of sustainability education.	LE1: I actively participate in digital learning activities related to sustainability. LE2: I pay continuous attention when using the digital learning system. LE3: I feel emotionally connected to the sustainability issues presented in the lessons. LE4: I am willing to spend extra time exploring sustainability-related resources. LE5: I ask questions or seek clarification when learning	(Fredricks *et al*., 2004); Thomas, 2016)

Table 1 (continue). Operational definition, questionnaire items, and reference.

Dimension	Operational Definition	Questions	References
		about sustainability through digital platforms. LE6: I share ideas and collaborate with peers during sustainability learning activities. LE7: I stay motivated even when the sustainability topics are challenging.	
Environmental Awareness (EA)	The level of students' cognitive, affective, and conative awareness regarding environmental issues, personal responsibility, and the tendency to adopt pro-environmental behaviors.	EA1: I am aware of the importance of sustainability for future generations. EA2: I recognize how my daily behaviors affect the environment. EA3: I feel personally responsible for contributing to environmental protection. EA4: I consider environmental consequences when making personal decisions. EA5: I am motivated to adopt environmentally friendly behaviors after engaging in sustainability learning.	(Lozano *et al*., 2017); Wals, 2012)

The questionnaire was first assessed for readability by students to ensure clarity and comprehensibility. It was then validated by two experts, both lecturers specializing in sustainability studies and elementary education. Revisions were made based on their feedback to improve the accuracy and contextual suitability of the items. Subsequently, a pilot test was administered to 102 fifth-grade students across three elementary schools in Bandung, conducted directly under teacher supervision. The pilot test confirmed the suitability of the instrument, and the results are summarized in **Table 2**. All questionnaire items tested met the criteria for both validity and reliability. Accordingly, the final questionnaire for this study consists of 18 items.

3.4. Data Analysis

Before the implementation of the personalized sustainability education program, students were informed about the study. Upon completion of the program, they were invited to voluntarily complete the questionnaire. The instrument employed a five-point Likert scale with response options ranging from "strongly disagree" to "strongly agree." The questionnaire was administered to students participating in digital sustainability education, and after several weeks of learning activities, a total of 114 valid responses were collected.

For data analysis, SPSS 22.0 (IBM, USA) was used to perform descriptive statistics and independent sample t-tests to examine differences in research variables across background characteristics. To test the hypothesized relationships, Smart-PLS 3.0 with Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed. PLS-SEM is widely recognized as a robust technique for testing predictive models and analyzing causal relationships among latent variables. Compared to covariance-based SEM (CB-SEM), which relies on covariance matrices, PLS-SEM is particularly advantageous in exploratory research, studies with smaller sample sizes, and complex models (Pavlou & Fygenson, 2006; Melchor & Julian, 2008).

The minimum sample size in PLS-SEM should be at least ten times the number of items associated with the most complex construct. In this study, the construct with the largest number of indicators was learner engagement, measured with eight items, suggesting a minimum requirement of 80 participants. With 114 valid responses, the sample size exceeded this threshold, ensuring sufficient statistical power. The PLS algorithm and bootstrapping procedure with 5,000 resamples were applied to estimate path coefficients and assess their significance (Henseler, 2010). This approach allowed for both the validation of the theoretical model and the evaluation of correlations and causal influences among personalized sustainability education, learner engagement, and environmental awareness.

Table 2. Empirical test results of the environmental awareness questionnaire.

Dimension	Item	Validity		Reliability		Conclusion
		Sig.	Criteria	Cronbach α	Criteria	
Personalized Sustainability Education (PSE)	1	0.000	Valid	0.910	High reliable	Included
	2	0.000	Valid			Included
	3	0.000	Valid			Included
	4	0.000	Valid			Included
	5	0.000	Valid			Included
	6	0.000	Valid			Included
Learner Engagement (LE)	7	0.000	Valid			Included
	8	0.000	Valid			Included
	9	0.000	Valid			Included
	10	0.000	Valid			Included
	11	0.000	Valid			Included
	12	0.000	Valid			Included
	13	0.000	Valid			Included
Environmental Awareness (EA)	14	0.000	Valid			Included
	15	0.000	Valid			Included
	16	0.000	Valid			Included
	17	0.000	Valid			Included
	18	0.000	Valid			Included

4. RESULTS AND DISCUSSION

4.1. Analysis of Background Variable

The subjects of this research consisted of 114 fifth-grade students from four provinces in Indonesia. In terms of age distribution, the majority of participants belonged to the younger age group, representing 81% of the total sample. **Table 3** provides a detailed breakdown of the age categories and their respective percentages.

4.2. Measurement Model

Cronbach's alpha values above 0.70 are generally considered acceptable and serve as the standard benchmark for evaluating reliability. Based on this criterion, all Cronbach's alpha values obtained in the present study can be regarded as reliable. Convergent validity and discriminant validity of the research model were assessed using Confirmatory Factor Analysis (CFA). Factor loadings are expected to meet a minimum threshold of 0.60 with a p-value less than 0.001, and all factor loadings in this study exceeded this requirement. Likewise, the benchmark for Composite Reliability (CR) is 0.70, and the CR values reported here were consistently above that standard. The cutoff value for Average Variance Extracted (AVE) is 0.50, and all AVE values in this study surpassed the recommended threshold. **Table 4** presents a summary of the means, standard deviations, items, constructs, factor loadings, AVE, CR, and Cronbach's alpha values for the survey instrument.

Table 3. Frequency distribution of sample data.

Items	Background Variables	Number of People	Percentage
Gender	Male	65	57%
	Female	49	43%
Age	9-10 years old	92	81%
	11-12 years old	22	29%
Location	Urban area	94	82%
	Semi-urban area	20	18%

Table 4. Measurement model parameter estimation.

Dimensions	Item	Factor Loading	AVE	CR	ProportionalC∝
PSE	PSE1	0.797	0.522	0.865	0.809
	PSE2	0.768			
	PSE3	0.803			
	PSE4	0.700			
	PSE5	0.734			
	PSE6	0.484			
LE	LE1	0.596	0.522	0.883	0.845
	LE2	0.565			
	LE3	0.775			
	LE4	0.684			
	LE5	0.784			
	LE6	0.774			
	LE7	0.836			
EA	EA1	0.601	0.525	0.845	0.771
	EA2	0.810			
	EA3	0.688			
	EA4	0.797			
	EA5	0.708			

From **Table 5**, the factor loadings of all questionnaire items exceed 0.70, thereby meeting the verification standard. The Cronbach's alpha and Composite Reliability (CR) values for all dimensions are also greater than 0.70, indicating strong reliability and internal consistency. In addition, the Average Variance Extracted (AVE) values for each dimension are above 0.50, demonstrating good convergent validity. As shown in **Table 4**, the square root of each AVE value on the diagonal is greater than the corresponding correlation coefficients in the matrix, further confirming discriminant validity. Moreover, the heterotrait–monotrait (HTMT) analysis presented in **Table 6** shows that all values are below 0.90, providing additional evidence of adequate discriminant validity.

4.3. Structural Equation Modelling Analysis

In evaluating structural equation modeling (SEM), it is crucial to ensure that collinearity issues are addressed. A Variance Inflation Factor (VIF) value greater than 5 typically indicates potential collinearity among dimensions. In this study, the VIF values ranged from 1.000 to 2.022, all well below the threshold of 5, suggesting no evidence of collinearity problems. To assess the overall fit of the PLS-SEM model, several commonly used indicators were applied, including SRMR, NFI, and RMS_theta. The SRMR value ranges between 0 and 1, with lower values reflecting a better model fit. The NFI index also ranges from 0 to 1, with values above 0.90 indicating a good fit. RMS_theta is applicable only for reflective measurement models, where values below 0.12 denote a satisfactory fit. In this study, the SRMR value was 0.109, indicating an acceptable fit. The NFI value was 0.634, which falls below the ideal threshold of 0.90 but remains moderately acceptable. The RMS_theta value was 0.196, slightly exceeding the recommended cutoff, yet still within a tolerable range. Overall, as summarized in **Table 7**, the results of the collinearity analysis and model fit suggest that the structural model demonstrates a generally adequate level of validity and reliability.

Table 5. Discriminant validity test (Fornell–Larcker).

	EA	LE	PSE
EA	0,725		
LE	0,684	0,723	
PSE	0,715	0,711	0,723

Table 6. Heterotrait–monotrait ratio of correlations.

	EA	LE	PSE
EA			
LE	0,812		
PSE	0,888	0,854	

Table 7. Collinearity analysis and model fit.

Dimension Correlation	VIF	Model Fit
PSE and EA	2,022	SRMR = 0,109
PSE dan LE	1,000	NFI = 0,634
LE dan EA	2,022	RMS_theta = 0,196

Next, model verification was carried out through path analysis and the coefficient of determination (R^2). In path analysis, the t-value is used to determine the significance of hypotheses. A t-value greater than 1.96 indicates significance at the 0.05 level (denoted by *), a t-value greater than 2.58 corresponds to the 0.01 level (denoted by **), and a t-value greater than 3.29 represents the 0.001 level of significance (denoted by ***). As shown in **Table 8**, hypotheses H1, H2, and H4 achieved a significance level with $p < 0.001$, while H3 reached significance at $p < 0.05$. **Table 8** also presents the path coefficients, which indicate the strength and direction of the relationships among the study variables. All coefficients were positive, confirming that personalized digital education contributes positively to different dimensions of learner engagement. In addition, the R^2 values reported in **Table 8** demonstrate that the model explains a substantial proportion of variance in the dependent constructs, further supporting the robustness of the proposed framework. Thus, all four hypotheses (H1, H2, H3, and H4) in this study are supported. **Figure 6** illustrates the PLS-SEM path analysis model.

Table 8. Path analysis verification.

Path Analysis	Path Coefficient	T Value	*p* Value	Hypothesis

PSE → EA	0,462	3,615	0,000	H1 valid
PSE → LE	0,711	15,296	0,000	H2 valid
LE → EA	0,356	2,861	0,004	H3 valid
PSE → LE → EA	0,253	3,513	0,000	H4 valid

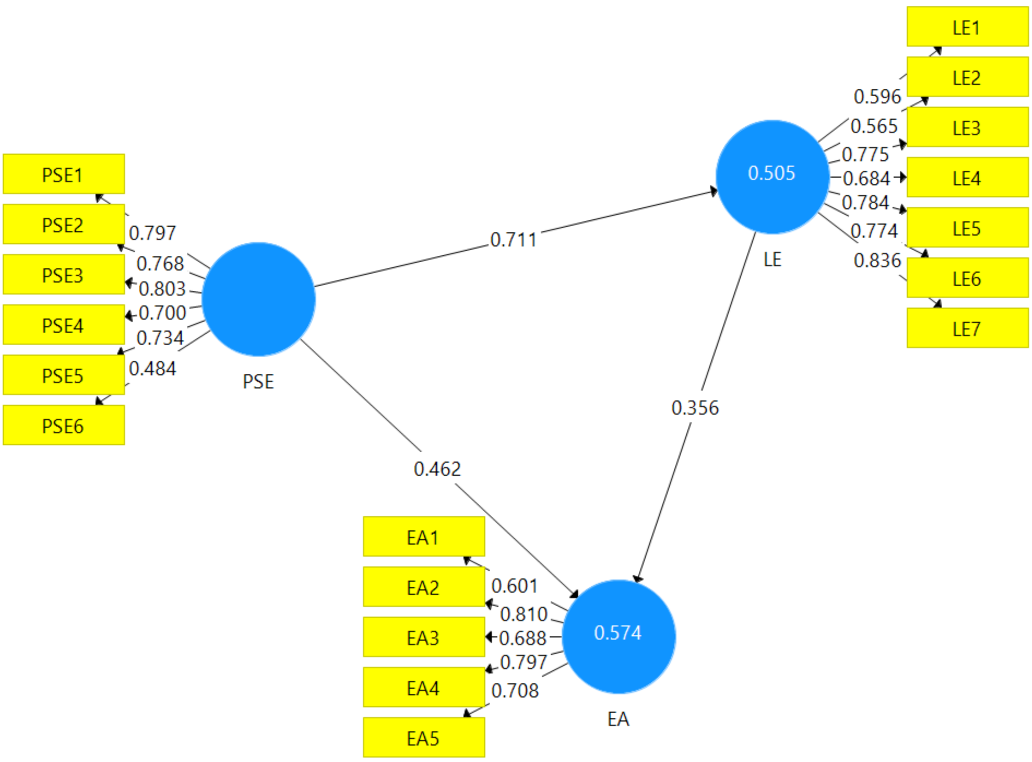

Figure 6. Model of PLS-SEM path analysis diagram.

The findings of this study provide important insights into the role of personalized sustainability education (PSE) in fostering learner engagement (LE) and environmental awareness (EA) among elementary school students in Indonesia. Structural model analysis confirmed all four hypotheses, showing that PSE directly enhances both LE and EA, while LE positively influences EA. Moreover, PSE indirectly promotes EA through the mediating role of LE.

First, the strong relationship between PSE and LE (H2) underscores the effectiveness of adaptive learning designs in increasing participation, attention, and emotional connection to sustainability content. This aligns with previous studies (Fredricks et al., 2004), which conceptualized engagement as integrating behavioral, emotional, and cognitive dimensions. Personalization strategies (such as adapting content to students' prior knowledge, interests, and local context) reduce cognitive overload, sustain motivation, and make learning more meaningful (Walkington *et al*., 2021). These results support previous literature (Wiek, 2011) for contextually relevant approaches in ESD, positioning engagement as central to transformative learning.

Second, the direct influence of PSE on EA (H1) suggests that personalized sustainability programs heighten ecological awareness, responsibility, and pro-environmental attitudes. This finding echoes previous reports (Lozano *et al*., 2017), who showed that interactive, learner-centered methods are more effective than traditional approaches. Similarly, connecting sustainability education with learners' lived experiences enhances relevance and accountability (Wals, 2012).

Third, the positive impact of LE on EA (H3) reinforces engagement as a catalyst for deeper learning and value internalization. Engaged learners critically process sustainability knowledge, connect it to personal experiences, and develop reflective attitudes that foster pro-environmental behaviors (Thomas, 2016). From a constructivist perspective (Chi & Wylie, 2014), engagement drives the active construction of meaning, thereby strengthening awareness and action.

Finally, the mediation effect of PSE on the LE–EA link (H4) demonstrates that personalization amplifies the pathway through which engagement fosters environmental awareness. Similar findings were reported in sustainable music education (Luo & Wang, 2025) and adaptive learning (Zhao *et al*., 2024), showing that personalization enhances self-efficacy, social responsibility, and awareness.

Theoretically, this study contributes to ESD literature by validating personalized education as both a direct driver and mediator of sustainability learning outcomes. Practically, it highlights the value of integrating adaptive digital technologies into school curricula to provide individualized learning pathways. Such efforts address learner diversity while bridging the knowledge-action gap in environmental education (Kollmuss & Agyeman, 2002; Bamberg & Möser, 2007). Finally, this study adds new information regarding SDGs, as reported elsewhere (**Table 9**).

Table 9. Previous studies on SDGs.

No	Title	Reference
1	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	(Awalussillmi *et al*., 2023)
2	Experimental demonstration for teaching the concept of steam engine power plant to vocational students to support the Sustainable Development Goals (SDGs) and its comparison to Indonesian Merdeka curriculum	(Fiandini *et al*., 2024)
3	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet SDGs needs	(Haq *et al*., 2024)
4	Techno-economic analysis of solar panel production from recycled plastic waste as a sustainable energy source for supporting digital learning in schools based on SDGs and science-technology integration	(Indra *et al*., 2025)
5	AR technology to stimulate creativity in a zero-waste lifestyle in converting plastic waste to art products to support SDGs	(Karyono *et al*., 2024)
6	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support SDGs 2030	(Keisyafa *et al*., 2024)
7	Enhancing professional readiness in vocational education through an integrative approach aligned with SDGs	(Khamdamovna, 2025)
8	Techno-economic analysis of eco-friendly bamboo-based paper production for child-friendly school media and SDGs	(Kholik *et al*., 2025)
9	SDGs in science education: Definition, literature review, and bibliometric analysis	(Maryanti *et al*., 2022)
10	Implementation of SDGs no. 12: Responsible production and consumption by optimizing lemon commodities	(Maulana *et al*., 2023)
11	Techno-economic feasibility of educational board game production from agro-industrial waste in support of SDGs	(Mukmin *et al*., 2025)
12	Computational calculation of adsorption isotherm characteristics of carbon microparticles prepared from mango seed waste to support SDGs	(Nandiyanto *et al*., 2023)

Table 9 (continue). Previous studies on SDGs.

No	Title	Reference
13	Silica microparticles with various sizes from bamboo leave waste for ammonia adsorption... to support SDGs	(Nandiyanto *et al.*, 2024)
14	Harnessing biomass for SDGs: Definition, bibliometric, application, opportunities, and challenges	(Nandiyanto *et al.*, 2025)
15	Fabrication of resin-based brake pad from snake fruit peel as sustainable renewable resources to support SDGs	(Nandiyanto *et al.*, 2024)
16	FTIR of pyrolysis of polypropylene microparticles and its chemical reaction mechanism... to support SDGs	(Nandiyanto *et al.*, 2024)
17	Adsorption isotherm characteristics of calcium carbon microparticles prepared from chicken bone waste to support SDGs	(Nandiyanto *et al.*, 2023)
18	Analysis of the application of Mediterranean diet patterns on sustainability to support SDGs	(Nurnabila *et al.*, 2023)
19	Biomass composition (cassava starch and banana peels) on mechanical and biodegradability properties of bioplastics for supporting SDGs	(Ragadhita *et al.*, 2023)
20	Biomass composition (cassava starch and banana peels) on mechanical and biodegradability properties of bioplastics for supporting SDGs	(Ragadhita *et al.*, 2022)
21	Safe food treatment technology: The key to realizing the SDGs zero hunger and optimal health	(Rahmah *et al.*, 2024)
22	Global warming: Promoting environmental awareness of senior secondary school students facing issues in the SDGs	(Supriatna *et al.*, 2024)
23	Profile of sustainable science teacher at junior high schools in Riau towards the SDGs	(Vilmala *et al.*, 2022)
24	School feeding program and SDGs in education: Linking food security to learning outcomes in Timor-Leste	(Ximenes, 2025)

5. CONCLUSION

This study investigates the impact of personalized sustainability education (PSE) on fostering learner engagement (LE) and environmental awareness (EA) among elementary school students in Indonesia. Adopting a quantitative, cross-sectional design, data were collected from 114 fifth-grade students across four provinces using validated measurement instruments. The hypothesized relationships were examined through Partial Least Squares Structural Equation Modeling (PLS-SEM). The results demonstrate that PSE has a significant positive effect on both LE and EA, while LE also positively contributes to EA. Furthermore, PSE was found to mediate the relationship between LE and EA, indicating that personalized and contextually relevant pedagogical strategies strengthen the transformation of engagement into awareness by making learning experiences more meaningful and relevant. This process ultimately deepens students' understanding and commitment to sustainability practices. Theoretically, this research advances the literature on personalized learning and Education for Sustainable Development (ESD) by offering empirical evidence of their integration within elementary education. Practically, the findings highlight the potential for schools to adopt digital personalization strategies that enhance learner engagement, foster environmental awareness, and nurture pro-environmental behaviors from an early age.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

8. REFERENCES

Aboussalah, A. M., Xu, Z., and Lee, C.-G. (2022). What is the value of the cross-sectional approach to deep reinforcement learning?. *Quantitative Finance*, *22*(6), 1091–1111.

Appleton, J. J., Christenson, S. L., and Furlong, M. J. (2008). Student engagement with school: Critical conceptual and methodological issues of the construct. *Psychology in the Schools*, *45*(5), 369–386.

Awalussillmi, I., Febriyana, K.R., Padilah, N., and Saadah, N.A. (2023). Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein. *ASEAN Journal of Agricultural and Food Engineering*, *2*(2), 113-120.

Bamberg, S., and Möser, G. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology*, *27*(1), 14–25.

Bernacki, M. L., and Walkington, C. (2018). The role of situational interest in personalized learning. *Journal of Educational Psychology*, *110*(6), 864–881.

Chi, M. T. H., and Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, *49*(4), 219–243.

Fiandini, M., Nandiyanto, A. B. D., and Muktiarni, M. (2024). Experimental demonstration for teaching the concept of steam engine power plant to vocational students to support the Sustainable Development Goals (SDGs) and its comparison to Indonesian Merdeka curriculum. *Journal of Engineering Science and Technology*, *19*(5), 1878–1905.

Fredricks, J. A., Blumenfeld, P. C., and Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109.

Haq, M.R.I., Nurhaliza, D.V., Rahmat, L.N., and Ruchiat, R.N.A. (2024). The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs. *ASEAN Journal of Economic and Economic Education*, *3*(2), 111-116.

Henseler, J., and Chin, W.W. (2010). A comparison of approaches for the analysis of interaction effects between latent variables using partial least squares path modeling. *Structural Equation Modeling: A Multidisciplinary Journal*, *17*(2010), 82–109.

Higgins, B., and Thomas, I. (2016). Education for sustainability in universities: Challenges and opportunities for change. *Australian Journal of Environmental Education*, *32*(1), 91–108.

Indra, S., Subagyo, A., Dyarini, and Nandiyanto, A. B. D. (2025). Techno-economic analysis of solar panel production from recycled plastic waste as a sustainable energy source for supporting digital learning in schools based on Sustainable Development Goals (SDGs) and science-technology integration. *Journal of Engineering Science and Technology*, *20*(4), 1149–1158.

Jarrett, L., and Takacs, G. (2020). Secondary students' ideas about scientific concepts underlying climate change. *Environmental Education Research*, *26*(3), 400-420.

Jian, Z. (2022). Sustainable engagement and academic achievement under impact of academic self-efficacy through mediation of learning agility—evidence from music education students. *Frontiers in Psychology*, *13*, 899706.

Karyono, T., Setiawan, T., and Permana, W. J. (2024). Augmented reality (AR) technology to stimulate creativity in a zero-waste lifestyle in converting plastic waste to art products to support Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *19*(4), 1463–1486.

Keisyafa, A., Sunarya, D.N., Aghniya, S.M., and Maula, S.P. (2024). Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030. *ASEAN Journal of Agricultural and Food Engineering*, *3*(1), 67-74.

Khamdamovna, K.S. (2025). Enhancing professional readiness in vocational education through an integrative approach aligned with the Sustainable Development Goals (SDGs). *ASEAN Journal for Science Education*, *4*(2), 143-154

Kholik, A., Suharsiw, Suradika, A., and Nandiyanto, A. B. D. (2025). Techno-economic analysis of eco-friendly bamboo-based paper production for child-friendly school media and sustainable development goals (SDGs). *Journal of Engineering Science and Technology*, *20*(5), 1582–1591.

Kollmuss, A., and Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior?. *Environmental Education Research*, *8*(3), 239–260.

Lorenzo de Reizabal, M. (2022). Music education models in the 21st century: the music mediation model for social engagement. *Revista Educación*, *46*(2), 666-686.

Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., and Lozano, F. J. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal. *Sustainability*, *9*(10), 1889.

Luo, K., and Wang, Y. (2025). Unraveling the pathways of sustainable music education: A moderated mediation analysis of environmental awareness, pedagogical approaches, and student engagement. *Frontiers in Psychology*, *16* (2025), 1554944.

Ma, W., Adesope, O. O., Nesbit, J. C., and Liu, Q. (2014). Intelligent tutoring systems and learning outcomes: A meta-analysis. *Journal of Educational Psychology*, *106*(4), 901–918.

Maryanti, R., Rahayu, N. I., Muktiarni, M., Al Husaeni, D.F., Hufad, A., Sunardi, S., and Nandiyanto, A. B. D. (2022). Sustainable Development Goals (SDGs) in science education: Definition, literature review, and bibliometric analysis. *Journal of Engineering Science and Technology*, *17*, 161–181.

Massy, P. J., and Sembiante, S. F. (2023). Pedagogical practices, curriculum development, and student experiences within postsecondary music education: A systematic literature review. *Research Studies in Music Education*, *45*(3), 600-615.

Maulana, I., Asran, M.A., and Ash-Habi, R.M. (2023). Implementation of sustainable development goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste. *ASEAN Journal of Community Service and Education*, *2*(2), 141-146.

Melchor, M.Q., and Julián, C.P. (2008). The impact of the human element in the information systems quality for decision making and user satisfaction. *Journal of Computer Information Systems*, *48*(2008), 44–52.

Meyer, J., Fleckenstein, J., and Köller, O. (2019). Expectancy value interactions and academic achievement: Differential relationships with achievement measures. *Contemporary Educational Psychology*, *58*, 58-74.

Mohan, L., Chen, J., and Anderson, C. W. (2009). Developing a multi-year learning progression for carbon cycling in socio-ecological systems. *Journal of Research in Science Teaching*, *46*(6), 675–698.

Mukmin, M. N., Sukoharsono, E. G., Rusydi, M. K., Prihatiningtias, Y. W., and Nandiyanto, A. B. D. (2025). Techno-economic feasibility of educational board game production from agro-industrial waste in support of Sustainable Development Goals (SDGs) through science and technology integration. *Journal of Engineering Science and Technology*, *20*(4), 1111–1120.

Nandiyanto, A. B. D., Al Husaeni, D. F., Ragadhita, R., Fiandini, M., Maryanti, R., and Al Husaeni, D. N. (2023). Computational calculation of adsorption isotherm characteristics of carbon microparticles prepared from mango seed waste to support Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *18*(2), 913–930.

Nandiyanto, A. B. D., Alhaqq, J. Y., Fiandini, M., Ragadhita, R., & Kurniawan, T. (2024). Silica microparticles with various sizes from bamboo leave waste for ammonia adsorption completed with bibliometric literature review, isotherm adsorption, and proposal adsorption mechanism to support Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *19*, 59–76.

Nandiyanto, A. B. D., Kurniawan, T., Bilad, M. R., and Farobie, O. (2025). Harnessing biomass for Sustainable Development Goals (SDGs): Definition, bibliometric, application, opportunities, and challenges. *Journal of Engineering Science and Technology*, *20*(4), 1047–1068.

Nandiyanto, A. B. D., Piantara, E., Alvani, C., Hafsah, D.W., Fathurohman, D., and Ragadhita, R. (2024). Fabrication of resin-based brake pad from snake fruit peel as sustainable renewable resources to support Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *19*(5), 2022–2037.

Nandiyanto, A. B. D., Putri, A. R., Pratiwi, V. A., Ilhami, V. I. N., Kaniawati, I., Kurniawan, T., Farobie, O., and Bilad, M. R. (2024). Fourier transform infrared spectroscopy (FTIR) of pyrolysis of polypropylene microparticles and its chemical reaction mechanism completed with computational bibliometric literature review to support sustainable development goals (SDGs). *Journal of Engineering Science and Technology*, *19*(3), 1090-1104.

Nandiyanto, A. B. D., Ragadhita, R., Fiandini, M., Al Husaeni, D. N., and Al Husaeni, D. F. (2023). Adsorption isotherm characteristics of calcium carbon microparticles prepared from chicken bone waste to support Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *18*(2), 1363–1379.

Nurnabila, A.T., Basnur, J., Rismayani, R., Ramadhani, S., and Zulhilmi, Z. (2023). Analysis of the application of mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production. *ASEAN Journal of Agricultural and Food Engineering*, *2*(2), 105-112.

Pavlou, P. A., and Fygenson, M. (2006). Understanding and predicting electronic commerce adoption: An extension of the theory of planned behavior. *MIS Quarterly*, *30*, 115-143.

Ragadhita, R., Fiandini, M., Nofiani, R., Farobie, O., Nandiyanto, A.B.D., Hufad, A., Mudzakir, A., Nugraha, W. C., and Istadi, I. (2023). Biomass composition (cassava starch and banana (Musa sp.) peels) on mechanical and biodegradability properties of bioplastics for supporting Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *18*(2), 228–238.

Ragadhita, R., Fiandini, M., Nofiani, R., Farobie, O., Nandiyanto, A.B.D., Hufad, A., Mudzakir, A., Nugraha, W. C., and Istadi, I. (2022). Biomass composition (cassava starch and banana (Musa sp.) peels) on mechanical and biodegradability properties of bioplastics for supporting Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *2022*, 228–238.

Rahmah, F.A., Nurlaela, N., Anugrah, R., and Putri, Y.A.R. (2024). Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health. *ASEAN Journal of Agricultural and Food Engineering*, *3*(1), 57-66.

Subban, P. (2006). Differentiated instruction: A research basis. *International Education Journal*, *7*(7), 935–947.

Supriatna, A., Tias, B., Hendayana, S., and Hernani, H. (2024). Global warming: Promoting environmental awareness of senior secondary school students facing issues in the

Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *19*(3), 1048–1064.

Susilawati, A. N., Kelana, J. B., and Ristiana, M. G. (2025). The use of STEM (science, technology, engineering, and mathematics) models to improve elementary school science concept understanding. *Jurnal Profesi Pendidikan*, *4*(1), 42-50.

Thomas, I. (2016). Critical thinking, transformative learning, sustainable education, and problem-based learning in universities. *Journal of Transformative Education*, *14*(4), 327–335.

Verbert, K., Manouselis, N., Ochoa, X., Wolpers, M., Drachsler, H., Bosnic, I., and Duval, E. (2012). Context-aware recommender systems for learning: A survey and future challenges. *IEEE Transactions on Learning Technologies*, *5*(4), 318–335.

Vilmala, B. K., Suhandi, A. N. D. I., Permanasari, A., and Kaniawati, I. (2022). Profile (Knowledge, Attitude, and Practice) of sustainable science teacher at junior high schools in Riau towards the Sustainable Development Goals (SDGs). *Journal of Engineering Science and Technology*, *5*(2), 1-8.

Walkington, C. A. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology*, *105*(4), 932–945.

Wals, A. E. J. (2011). Learning our way to sustainability. *Journal of Education for Sustainable Development*, *5*(2), 177–186.

Wang, X., and Huang, W. (2024). Examining students' music listening willingness and engagement to foster their musical achievement and development in higher educational institutions. *Scientific Reports*, *14*(1), 3036.

Wardani, D. S., Wulandari, M. A., Nurfurqon, F. F., and Kurniawati, D. (2021). Stem-integrated project-based learning (pjbl) model and lecture with experiments learning model: what is the scientific literacy skills of elementary teacher education students in these learning models?. *Al-Bidayah: Jurnal pendidikan Dasar Islam*, *13*(1), 55-72.

Wetering, J.V.D., Leijten, P., Spitzer, J., and Thomaes, S. (2022). Does environmental education benefit environmental outcomes in children and adolescents? A meta-analysis. *Journal of Environmental Psychology*, *81*(101782), 1-12.

Wiek, A., Withycombe, L., and Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, *6*(2), 203–218.

Ximenes, S.M. (2025). School feeding program and Sustainable Development Goals (SDGs) in education: Linking food security to learning outcomes in Timor-Leste. *ASEAN Journal for Science Education*, *4*(2), 155-168

Zhang, J., and Cao, A. (2025). Environmental attitudes, self-efficacy, and social norms as mediators of the effects of education for sustainable development on pro-environmental behavior among university students. *Sustainability*, *17*(3), 933.

Zhao, Y., Zhang, W., and Li, J. (2024). Enhancing pro-environmental behavior through nature-contact environmental education: The mediating roles of environmental attitudes and responsibility. *Frontiers in Environmental Science*, *12*, 1491780.