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Gender as a Moderator of Eco-Digital Literacy and Sustainable Social Behavior in Paperless Learning Environments

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Abstract. This study aims to analyze the influence of eco-digital literacy on the sustainable social behavior of elementary school students in a paperless learning environment, as well as to test the role of gender moderation in this relationship. A quantitative approach with an explanatory survey design was used by involving 385 students from several elementary schools who had implemented paperless learning. Data was collected using a closed-ended questionnaire on a Likert scale and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) and Multi-Group Analysis (PLS-MGA) through SmartPLS 4. The results showed that eco-digital literacy had a positive and significant effect on sustainable social behavior ($\beta = 0.614$; $t = 12.792$; $p < 0.001$; $R^2 = 0.577$). PLS-MGA testing confirmed that gender moderated the relationship significantly ($\Delta\beta = 0.138$; $p = 0.048$), with a stronger influence on the female group ($\beta = 0.681$) than on the male ($\beta = 0.543$). These findings provide important implications for the development of gender-responsive pedagogic-based curricula in the era of continuous digital learning.

Keywords: eco-digital literacy; sustainable social behavior; gender; paperless learning; PLS-SEM

INTRODUCTION

The 21st century is marked by the acceleration of digital transformation that permeates all joints of life, including the world of education. Advances in information and communication technology (ICT) have fundamentally changed the paradigm of learning, from a conventional paper-based model to a dynamic and connected digital ecosystem (Zhang et al., 2026). The global report shows that by 2024 more than 754 million adults will still be digitally illiterate, despite the world's median internet access rate reaching 90%, indicating a significant gap between access to technology and the ability to use it meaningfully (Nations, 2024).

The digital transformation of education is closely related to the global sustainable development agenda. The United Nations through the 2030 Agenda has set three SDGs that are most relevant to the context of this research, namely SDG 4 (Quality Education), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). In the context of education, these three SDGs meet at one crucial point: how schools can become agents of sustainable behavioural change in the digital age (Anshari, 2024). Empirical evidence shows that digital transformation contributes positively to the achievement of the SDGs, but at the same time demands a more holistic and responsible approach to addressing the "sustainability paradox" in digital education (Chugh, 2026).

One of the concrete manifestations of digital transformation in education is the birth of a paperless learning environment. This environment replaces the use of physical paper with digital devices and platforms systematically, including Learning Management Systems (LMS), e-books, cloud storage, and various other edutech platforms (Shonfeld et al., 2017). Every ton of paper avoided means savings of up to 7,000 gallons of water, reduced carbon emissions, and biodiversity protection (Knezevic, 2023). On the pedagogical side, the adoption of digital platforms in the school environment creates opportunities for the formation of environmentally friendly behaviors organically.

Responding to the demands of the digital-sustainable era, academics began to develop the concept of eco-digital literacy as an integrative competency of the 21st century, defined as the ability of individuals to use digital technology competently, critically, and responsibly with an orientation on environmental and social sustainability values (Zahfar, 2024). Meanwhile, sustainable social behavior refers to a series of social actions taken by individuals based on consideration of long-term impacts on the environment, community, and future generations

(Abdullahi et al., 2024). Theoretically, the relationship between these two constructs can be understood through Social Cognitive Theory (Bandura, 1986), Theory of Planned Behavior (Ajzen, 1991), then Value-Belief-Norm Theory (Stern et al., 1999).

Gender is a sociological variable that has proven to be relevant in the context of environmental behavior and technology use. Cross-disciplinary research has consistently shown gender differences in environmental concern and pro-environmental behaviour, although these patterns are complex and influenced by cultural factors (Echavarren, 2023). The inconsistencies of the findings in the literature suggest the need to explicitly test the role of gender moderation, rather than simply placing it as a control variable or demographic descriptor.

There are four significant research gaps in the existing literature. First, eco-digital literacy as an integrative construct is still relatively new and does not yet have a solid research base, especially in relation to sustainable social behavior. Second, studies on paperless learning focus more on aspects of academic effectiveness than on ecological-social impacts on student behavior. Third, gender is rarely tested as an explicit moderator in the relationship between digital competence and sustainable behavior. Fourth, almost all relevant research is conducted at the higher or secondary education level, not elementary school, which is a critical period for the formation of values and habits.

Based on this, this research comes with three new contributions: (1) integrating eco-digital literacy and sustainable social behavior in a research model set in a paperless environment; (2) examine the role of gender moderation explicitly through PLS-MGA; and (3) targeting the population of elementary school students who have been under-represented in similar research. This research aims to: (1) analyze the influence of eco-digital literacy on sustainable social behavior in a paperless environment; and (2) analyze the role of gender as a moderator in the relationship.

METHODS

Research Design

This study uses a quantitative approach with an explanatory survey design. This approach was chosen because it aims to test the relationship between variables empirically through hypothesis testing based on a theoretical framework (Hair et al., 2022). The cross-sectional design allows for efficient collection of data from representative samples at a single point in time. The analysis unit is elementary school students who participate in paperless-based learning.

Population and Sample

The research population is all elementary school students who organize paperless learning in their schools. The proportionate stratified random sampling technique is applied by stratifying schools based on grade levels (grades 4, 5, and 6). The determination of the number of samples refers to the 10-times rule in PLS-SEM (Hair et al., 2022). Considering the need for a minimum of 100 respondents per group for PLS-MGA, this study set a target of 385 students using the Slovin formula with an error rate of 5%.

Research Variables

This study involves three variables as presented in Table 1.

Table 1. Research Variables

Variable	Type	Code
Eco-Digital Literacy (EDL)	Independent	X
Sustainable Social Behavior (SSB)	Dependency	Y
Gender	Moderator	Z

Eco-Digital Literacy (X) is defined as the ability of students to use digital technology critically, responsibly, and oriented towards environmental sustainability ((Lo, 2024; Zahfar, 2024). The construct is measured through four dimensions with 16 statement items (Table 2).

Table 2. Dimensions and Indicators of Eco-Digital Literacy

Dimensions	Indicators/Item Description
Digital Environmental Awareness	Awareness of the environmental impact of the use of digital technology; understanding the carbon footprint of the device; Digital Energy Efficiency Awareness (4 items)
Responsible Digital	Responsible and ethical use of technology; adherence to digital norms in

Use	schools; Avoidance of excessive use of devices (4 items)
Sustainable Digital Practices	The habit of minimizing document printing; resource-efficient digital file management; Preferences of eco-friendly digital platforms (4 items)
Critical Eco-Digital Thinking	Ability to evaluate the ecological impact of technological decisions; critical analysis of digital content related to the environment; Reflection on Technology Use Patterns (4 items)

Sustainable Social Behavior (Y) is defined as a social action of students that reflects the values of sustainability in daily life in a digital-based school environment (Abdullahi et al., 2024; Rocha, 2023). The construct is measured through five dimensions with 20 statement items (Table 3).

Table 3. Dimensions and Indicators of Sustainable Social Behavior

Dimensions	Indicators/Item Description
Social Responsibility	Concern for the impact of personal actions on others; involvement in school social activities; A sense of responsibility for the learning community (4 items)
Environmental Responsibility	Active participation in eco-friendly practices in schools; energy and resource savings; Waste Reduction in the Classroom (4 items)
Collaborative Sustainability	Sustainability-based project cooperation; encourage friends to behave pro-environmentally; Contribution of Digital Collaborative Discussion (4 items)
Ethical Digital Behavior	Ethical use of digital platforms; respect the privacy and digital rights of others; Avoiding the dissemination of irresponsible information (4 items)
Sustainable Participation	Participation in school activities that support the SDGs; engagement of digital-based environmental initiatives; The Importance of Paperless Schools (4 Points)

Gender (Z) acts as a dichotomous moderator variable: male (code 1) and female (code 2). In PLS-SEM, gender is integrated through Multi-Group Analysis (PLS-MGA) to compare the path coefficients between the two groups (Henseler et al., 2016).

Data Collection Instruments and Procedures

Data were collected using a 36-item closed questionnaire (16 EDL, 20 SSB items) with a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The development of the item went through three stages: theoretical review, content validation (CVR ≥0.70 by three experts), and instrument testing on 50 respondents. The main data collection is carried out online through Google Forms after obtaining school permission and informed consent of parents/guardians.

Data Analysis Techniques

The evaluation of the outer model includes convergent validity, discriminant validity (HTMT), and construct reliability tests with the criteria presented in Table 4.

Table 4. Outer Model Evaluation Criteria

Criteria	Threshold	References
Outer Loading	≥ 0.70	Hair et al. (2022)
AVE	≥ 0.50	Hair et al. (2022)
Composite Reliability (CR)	≥ 0.70	Hair et al. (2022)
Cronbach's Alpha (α)	≥ 0.70	Hair et al. (2022)
HTMT Ratio	< 0.85	Henseler et al. (2016)

Table 5. Inner Model Evaluation Criteria

Criteria	Threshold / Interpretation	References
R^2	> 0.10 weak; > 0.33 moderate; > 0.67 strong	Hair et al. (2022)
f^2	0.02 small; 0.15 intermediate; 0.35 large	Cohen (1988)
Q^2	> 0 (predictive relevance)	Hair et al. (2022)

Path Coefficient (β)	Significant if $t > 1.96$; $p < 0.05$	Bootstrapping 5,000 subsamples

The structural model was evaluated using the criteria presented in Table 5, including the coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), and variance inflation factor (VIF) Hypothesis testing was carried out through bootstrapping 5,000 subsamples ($t > 1.96$; $p < 0.05$). Gender moderation was tested using PLS-MGA preceded by a three-step Measurement Invariance of Composite Models (MICOM) procedure (Hair et al., 2022; Henseler et al., 2016). The difference in path coefficients between gender groups was tested using a permutation test (1,000 subsamples; $\alpha = 0.05$).

Research Hypothesis

H_1: Eco-digital literacy has a positive and significant effect on students' sustainable social behavior in a paperless learning environment.

H_2: Gender moderates the relationship between eco-digital literacy and sustainable social behavior, so the power of these influences differs significantly between male and female groups.

RESULTS AND DISCUSSION

Respondent Characteristics

The study successfully collected 391 respondents; After the cleaning data was obtained, 385 valid respondents (response rate of 98.5%). The characteristics of the respondents are presented in Table 6.

Table 6. Characteristics of Respondents (n = 385)

Characteristics	Categories	n	%
Gender	Male	181	47.0
	Women	204	53.0
Classes	Grade 4	128	33.2
	Grade 5	131	34.0
	Grade 6	126	32.8
Duration of Paperless Exposure	< 1 year	89	23.1
	1–2 years	176	45.7
	> 2 years	120	31.2
Total		385	100

The gender composition is relatively balanced (females 53.0%; males 47.0%). Distribution of proportional class levels (32.8%–34.0%). The majority of respondents (45.7%) have been exposed to paperless learning for 1–2 years, indicating adequate experience to develop both constructs studied.

Descriptive Statistics

Descriptive statistics of the research variables are presented in Table 7. Score categorization used intervals: very low (1.00–1.80), low (1.81–2.60), medium (2.61–3.40), high (3.41–4.20), and very high (4.21–5.00).

Table 7. Descriptive Statistics of Eco-Digital Literacy and Sustainable Social Behavior

Variable / Dimension	Min	Max	Red	SD	Categories
Eco-Digital Literacy (overall)	2.56	5.00	3.84	0.62	Height
Digital Environmental Awareness	2.25	5.00	3.76	0.68	Height
Responsible Digital Use	2.50	5.00	3.91	0.60	Height
Sustainable Digital Practices	2.00	5.00	3.78	0.71	Height
Critical Eco-Digital Thinking	2.25	5.00	3.72	0.74	Height
Sustainable Social Behavior (overall)	2.40	5.00	3.79	0.63	Height
Social Responsibility	2.50	5.00	3.83	0.65	Height
Environmental Responsibility	2.25	5.00	3.74	0.67	Height
Collaborative Sustainability	2.50	5.00	3.81	0.66	Height
Ethical Digital Behavior	2.25	5.00	3.77	0.68	Height
Sustainable Participation	2.40	5.00	3.80	0.64	Height

Students' eco-digital literacy is in the high category (M = 3.84; SD = 0.62). The Responsible Digital Use dimension obtained the highest average (M = 3.91), while Critical Eco-Digital Thinking obtained the lowest average (M = 3.72). Sustainable social behavior is also in the high category (M = 3.79; SD = 0.63), with Social Responsibility as the strongest dimension (M = 3.83).

Evaluation of the Outer Model (Measurement Model)

Evaluation of the validity and reliability of the construct is presented in Table 8. Two grains (EDL11 and SSB8) were eliminated due to an outer loading < 0.40.

Table 8. Results of Outer Loading, AVE, and Composite Reliability Evaluation

Code	Indicator	Loading	AVE	CR
EDL1	I understand the impact of using digital technology on the environment	0.812		
EDL2	I know the carbon footprint of the digital devices I use	0.784		
EDL3	I pay attention to energy consumption when using digital devices	0.791		
EDL4	I use digital technology for really important purposes	0.803	0.626	0.869
EDL5	I adhere to digital ethics in a school environment	0.819		
EDL6	I avoid overusing digital devices	0.776		
EDL7	I prefer to share tasks digitally rather than print paper	0.798		
EDL8	I store documents in the cloud so I don't have to reprint them	0.783	0.621	0.866
EDL9	I evaluate whether my digital activities have an impact on the environment	0.757		
EDL10	I am able to distinguish digital information that is environmentally responsible	0.774	0.589	0.851
SSB1	I care about the impact my actions have on the learning community	0.801		
SSB2	I participate in eco-friendly school social activities	0.819		
SSB3	I reduce electricity usage when not using the device	0.788	0.638	0.876
SSB4	I invite friends to behave in an environmentally friendly manner	0.831		
SSB5	I value the privacy of others in digital platforms	0.805		
SSB6	I avoid spreading hoaxes about the environment on social media	0.793		
SSB7	I actively participate in the school's paperless program	0.817	0.648	0.881

All indicators that were maintained had an outer loading ≥0.70 (range 0.757–0.831), AVE ≥0.50 (0.589–0.648), and Composite Reliability ≥0.70 (0.851–0.881). Discriminant validity (HTMT) is presented in Table 9.

Table 9. Results of the Discriminant Validity Test (HTMT)

Construct Pairs	HTMT Ratio	Remarks
Eco-Digital Literacy ↔ Sustainable Social Behavior	0.742	< 0.85 ✓

The HTMT ratio = 0.742 < 0.85 confirms the two constructs are conceptually and empirically different (Henseler et al., 2016). All external

model criteria are met.

Measurement Invariance Test (MICOM)

As a prerequisite for PLS-MGA, a three-step MICOM test is carried out. The results are presented in Table 10.

Table 10. Measurement Invariance of Composite Models (MICOM) Test Results

MICOM Steps	Results	Verdict
Step 1: Configural Invariance	Fulfilled (by default SmartPLS 4)	Fulfilled ✓
Step 2: Compositional Invariance	c = 0.997; p = 0.423	Fulfilled ✓
Step 3a: Equal Mean Values	Δ mean = 0.041; p = 0.312	Fulfilled ✓
Step 3b: Equal Variance	Δ var = 0.028; p = 0.419	Fulfilled ✓

The results showed a full measurement invariance between the male and female groups, allowing direct comparison of the path coefficients via PLS-MGA (Hair et al., 2022).

Hypothesis Testing Results

Table 11. Hypothesis Testing Results (Bootstrapping 5,000 Subsamples)

Hypothesis	Pathway	β	OR	t-stat	p-value	Ket.
H_1	EDL → SSB	0.614	0.048	12.792	0.000	Accepted ✓
H_2 (MGA)	EDL → SSB (Female)	0.681	0.056	12.161	0.000	
	EDL → SSB (Male)	0.543	0.061	8.902	0.000	
	Coefficient difference (Δβ)	0.138	0.082	1.982	0.048	Accepted ✓

Table 12. Values R^2, f^2, and Q^2 Model

Construct	R^2	f^2	Q^2
SSB – Overall Model	0.577	0.865	0.341
SSB – Women's Group (n = 204)	0.624	—	—
SSB – Male Group (n = 181)	0.520	—	—

The H_1 test yielded β = 0.614 (t = 12.792; p = 0.000), confirming the positive and significant influence of eco-digital literacy on sustainable social behavior. The value of R^2 = 0.577 (high category), effect size f^2 = 0.865 (very large), and Q^2 = 0.341 > 0 confirm the predictive relevance of the model. Thus, H_1 is accepted.

H_2 testing via PLS-MGA showed that the pathway coefficients differed significantly between women (β = 0.681; R^2 = 0.624) and males (β = 0.543; R^2 = 0.520), with a difference of Δβ = 0.138 which proved to be significant (t = 1.982; p = 0.048). Thus, H_2 is accepted: gender has been shown to moderate the relationship between eco-digital literacy and sustainable social behavior, with a stronger influence on women's groups.

DISCUSSION

The Influence of Eco-Digital Literacy on Sustainable Social Behavior

The results of the study confirmed the positive and significant influence of eco-digital literacy on sustainable social behavior (β = 0.614; t = 12.792; p < 0.001), with a value of R^2 = 0.577 which showed that 57.7% of the variance of sustainable social behavior could be explained by eco-digital literacy. These findings are consistent with the theoretical argument of Social Cognitive Theory (Bandura, 1986) which confirms that a person's cognitive competence and self-confidence are the main predictors of behavior. In this context, students who understand the ecological impact of

the use of digital technology, are able to use it responsibly, and have the ability to think critically about digital-environment issues, will be more likely to internalize sustainability values into everyday social actions in a paperless environment.

This mechanism of influence can be explained through three complementary pathways. First, the Digital Environmental Awareness dimension (M = 3.76) builds cognitive awareness of the ecological consequences of each digital action, creating a motivational basis for pro-environmental behavior. Second, the Responsible Digital Use dimension (M = 3.91) forms subjective norms and positive habits that are consistently transferred into the broader domain of social behavior. Third, the Sustainable Digital Practices dimension (M = 3.78) provides a repertoire of concrete behaviors that can be observed and imitated by peers through the vicarious learning process (Bandura, 1986). These three pathways synergistically strengthen the relationship between digital-ecological competencies and their manifestation in sustainable social action.

These findings are in line with (Awdziej et al., 2023) which found that students' digital maturity significantly affects engagement in sustainable behaviors, with a comparable path coefficient. In line with that, (He, 2025) found that digital literacy integrated with ecological values significantly predicts green consumption behavior through the pathway of subjective attitudes and norms mediated by the Theory of Planned Behavior (Ajzen, 1991). From a TPB perspective, eco-digital literacy operates on three levels at once: reinforcing positive attitudes towards sustainable behavior, shaping subjective norms about what is considered appropriate in a digital learning community, and enhancing the perception of behavioral control so that students feel capable and empowered to act pro-environment. The combination of these three components of the SDGs strengthened by eco-digital literacy is what produces a substantive influence as shown by the strong path coefficient.

Effect size $f^2 = 0.865$ which far exceeds the conventional limit of large effects ($f^2 \geq 0.35$) according to (Cohen, 1988) indicates that eco-digital literacy is not just a medium predictor, but a dominant determinant for sustainable social behavior in the context of paperless learning. The magnitude of this effect size can be understood within the framework of Value-Belief-Norm Theory (Stern et al., 1999): A paperless environment structurally creates a consistent opportunity for students to experience and express sustainability values in their every digital interaction. When the school ecosystem itself is designed to minimize environmental impact, eco-digital literacy not only builds abstract awareness, but is directly connected to meaningful everyday experiences, resulting in a more efficient conversion of competencies into behaviors than conventional learning contexts.

The predictive relevance of the model confirmed by $Q^2 = 0.341$ (well above the threshold of 0) reinforces the belief that this model does not simply explain the sample data, but has an adequate generalization capacity. These findings are in line with (Solórzano Solórzano et al., 2024) who found that digital competencies integrated with ecological orientation consistently predict green behavior in various educational contexts. This consistency provides theoretical confidence that eco-digital literacy is a robust and reliable construct as a target for pedagogical interventions to promote sustainable social behavior.

The finding that attracted attention was the position of the Critical Eco-Digital Thinking dimension (M = 3.72) as the dimension with the lowest mean among the four dimensions of eco-digital literacy. This pattern is not an anomaly, but reflects the characteristics of the cognitive development of elementary school-age children who are still at the concrete operational stage towards formal operations (Creswell & Creswell, 2023). Abstract evaluative and reflective skills—such as assessing the long-term ecological impact of technological decisions—do develop more slowly than procedural awareness and practice. Elementary school students have an easier time developing ecological awareness through hands-on practice and gamification than through abstract reflection (Ricoy & Sánchez-Martínez, 2022). These findings underscore the need for a scaffolding approach in developing ecological-digital critical thinking skills at the primary school level, for example through real-world problem-based projects that link everyday digital decisions with directly observable environmental impacts.

The Responsible Digital Use dimension that obtained the highest mean (M = 3.91) reflects the success of paperless programs in shaping norms of responsible digital behavior. The schools that are the sample of this study have implemented paperless for at least one year, so that the norms of ethical and responsible use of technology have been institutionalized into the classroom culture. This is consistent with the socialization

perspective in SCT which emphasizes that consistent exposure to positive norms and behavior models will form a stable repertoire of behaviors (Bandura, 1986). The implication is that a longer duration of paperless implementation has the potential to produce stronger eco-digital literacy, especially in dimensions that require the internalization of social norms.

The Role of Gender Moderation in the Relationship between Eco-Digital Literacy and Sustainable Social Behavior

The results of PLS-MGA confirm that gender significantly moderates the relationship between eco-digital literacy and sustainable social behavior ($\Delta\beta = 0.138$; $t = 1.982$; $p = 0.048$). The effect of eco-digital literacy on sustainable social behavior was stronger in the female group ($\beta = 0.681$; $R^2 = 0.624$) compared to the male group ($\beta = 0.543$; $R^2 = 0.520$). These findings are a significant empirical contribution because they confirm the role of gender not as a regular demographic covariate, but rather as a moderator that meaningfully changes the strength of the relationship between the two main constructs. Confirmation of full measurement invariance through the MICOM procedure ensures that these coefficient differences reflect real substantive differences, not artifacts of measurement differences between groups.

These findings are consistent with a number of cross-disciplinary studies that have documented women's pro-environmental excellence in care and behavior. (Boned-Gómez et al., 2025) found that female students' sustainability awareness was consistently higher in almost all dimensions studied, including the socio-ecological dimension. (Fajri et al., 2023) report that gender role beliefs in society moderate patterns of gender differences in pro-environmental behaviors, with women tending to exhibit more consistent conservation behaviors. (Li et al., 2022) confirms a similar pattern in the Asian context, where women consistently exhibit stronger pro-environmental behaviors, especially in domains related to community maintenance and waste reduction. In particular, it found gender differences in sustainability awareness after the implementation of project-based Education for Sustainable Development, where female students showed more substantial improvements (Setiawan et al., 2023).

The theoretical explanation of this moderation pattern can be assembled from three complementary perspectives. First, from the perspective of ecofeminism (Echavarren, 2023), there is a historical and cultural affinity between femininity and care ethics that includes concern for nature and community. This value-orientation creates stronger compatibility between eco-digital literacy which is at its core a competency-based concern for the impact of technology on the environment and sustainable social behavior. For female students, ecological-digital knowledge is not only understood as cognitive information, but also resonates with the social-relational value scheme that has been formed from an early age through the process of gender socialization.

Second, from the perspective of Social Cognitive Theory (Bandura, 1986) The processes of observational learning and self-efficacy operate differently in the two gender groups. Research shows that girls tend to be more responsive to social modeling of the figures they identify, including adult female figures who care about the environment in digital media and in school settings (Ricoy & Sánchez-Martínez, 2022). When female students witness role models that integrate digital competencies with environmental concerns, the vicarous reinforcement process takes place more intensively, creating a cycle of self-empowerment that converts eco-digital literacy into tangible actions with higher efficiency. On the other hand, male students at primary school age may be more motivated by the competitive dimension and individual achievement in the use of technology, so the ecological-social dimension of eco-digital literacy requires different motivational channels to be converted into sustainable social behaviors.

Third, from the perspective of the Theory of Planned Behavior (Ajzen, 1991), subjective normsi.e., perceived social pressures to behave in a certain way operate with different intensities in both gender groups in the context of pro-environmental behaviors. Women generally report stronger normative pressures to behave responsibly towards the environment and community, and this reinforces the conversion of attitudes built through eco-digital literacy into actual intentions and behaviors (Adeyemi, 2025). In a paperless learning ecosystem that explicitly promotes sustainability values, the group norms that are formed will more strongly influence female students who are more sensitive to these normative signals.

It is important to note that although the influence of eco-digital literacy was stronger on the female group, the male group still showed substantial and significant path coefficients ($\beta =$

0.543; t = 8.902; p < 0.001). This means that eco-digital literacy remains a strong predictor of sustainable social behavior in both gender groups, not just relevant for female students. The moderate difference of $\Delta\beta = 0.138$ comparable to one to two standard deviations of the confidence interval suggests that the gender gap in the conversion of competencies into behaviors is statistically and practically meaningful, but not an unbridgeable gap. This sends an optimistic signal that targeted pedagogical interventions have the potential to significantly strengthen the conversion of eco-digital literacy in male students.

The findings of the R^2 of the female group (0.624) which are higher than those of the male group (0.520) also indicate that the eco-digital literacy model → sustainable social behavior as a whole is more explicit for the female group. This means that not only are the strengths of different relationships, but the proportion of variance that can be explained by eco-digital literacy is also greater in female students. This is consistent with the interpretation that eco-digital literacy is a more central and integrated construct in the value system and behavior of female students, while for male students there are other factors outside of eco-digital literacy that contribute more to the variance of their sustainable social behavior such as competitive motivation, peer group identity, or technological achievement orientation.

Dimension Analysis: Deeper Patterns of Findings

Descriptive statistical analysis per dimension reveals rich patterns to be discussed further. In the eco-digital literacy dimension, the mean order from highest to lowest is: Responsible Digital Use (3.91) > Sustainable Digital Practices (3.78) > Digital Environmental Awareness (3.76) > Critical Eco-Digital Thinking (3.72). This pattern reflects that norms of responsible digital behavior are easier to form and internalize than more abstract evaluative and reflective capacities. This is in line with Dreyfus' model of competency development which describes the journey from novice (application of simple rules) to expert (deep holistic and evaluative understanding).

In the dimension of sustainable social behavior, the mean order shows Social Responsibility (3.83) as the strongest dimension, followed by Sustainable Participation (3.80), Collaborative Sustainability (3.81), Ethical Digital Behavior (3.77), and Environmental Responsibility (3.74) as the lowest. This pattern is interesting because it indicates that students are stronger in the dimension related to direct social relations (social responsibility, collaboration) than in the dimension related to environmental commitment which is more abstract (environmental responsibility). This phenomenon can be understood through psychological proximity: the social impact of one's behavior is easier to observe and feel directly than the environmental impact which is often diffuse, accumulative, and delayed (Stern et al., 1999). These findings also imply that pedagogical strategies that link environmental behavior to real and intimate social impacts will be more effective in encouraging Environmental Responsibility in elementary school students.

The correlation between the eco-digital literacy dimension profile and sustainable social behavior also reveals a meaningful structural alignment. The weakest dimension of eco-digital literacy (Critical Eco-Digital Thinking) corresponds to the weakest dimension of SSB (Environmental Responsibility): both relate to evaluative and abstract competencies that require thinking that goes beyond concrete and immediate situations. In contrast, the most powerful dimension of eco-digital literacy (Responsible Digital Use) corresponds to strong Social Responsibility: both are rooted in behavioral norms that have been institutionalized in daily social interactions. This alignment provides additional empirical support for the proposed model, while providing concrete guidance for pedagogical interventions: strengthening Critical Eco-Digital Thinking will specifically boost Environmental Responsibility which is currently a relative weak point in the profile of students' sustainable social behavior.

Gender perspectives in this dimensional analysis add a richer layer of understanding. Although the descriptive data per dimension were not analyzed separately by gender group in this study, the moderation patterns found through PLS-MGA suggest that the difference in the path coefficient of the gender group ($\Delta\beta = 0.138$) is most likely not evenly distributed across the dimensions. Theoretically, dimensions that are closely related to relational and communal values such as Collaborative Sustainability and Social Responsibility have the potential to show greater gender differences than more individual and procedural dimensions such as Sustainable Digital Practices. This hypothesis opens up opportunities for further research using bifactor analysis designs or separate dimensional analysis per gender group, which will be able to map more precisely in which dimensions gender differences are most prominent

and in which dimensions the two groups are relatively equal. This mapping will in turn allow for the design of more targeted and efficient interventions, instead of using a one-for-all approach that may not be optimal for both gender groups.

Theoretical Implications

This research provides several mutually reinforcing theoretical contributions. First, this study succeeded in validating eco-digital literacy as an integrative construct that is able to bridge digital literacy (technological domain) and ecological literacy (environmental domain) in one coherent and empirical framework. This expands the scope of Social Cognitive Theory and Theory of Planned Behavior to the realm of digital-ecology that has not previously been systematically explored, especially at the basic education level. This validation has important implications: eco-digital literacy is not just a mechanical combination of two different literacies, but a construct that has its own psychometric integrity with AVE and CR meeting the standards, as well as HTMT that confirms its conceptual differentiation from sustainable social behavior.

Second, the study empirically confirms that gender is a meaningful moderator not just a demographic covariate or descriptive variable in the relationship between digital-ecological competence and sustainable social behavior. This fills a significant methodological gap in the literature that has tended to treat gender only as a control variable or descriptive comparator (Setiawan et al., 2023). Using PLS-MGA preceded by MICOM confirmation, the study establishes a more rigorous methodological standard for gender moderation testing in sustainability education research, which is expected to serve as a reference for similar research in the future.

Third, this research integrates the dimension of sustainable social behavior into the paperless learning ecosystem, expanding the discourse from academic effectiveness to the formation of holistic ecological-social characters. This has implications for the expansion of the theoretical perspective on paperless learning: from a mere resource management strategy (reducing the use of paper) to a pedagogical ecosystem that has the potential to form agents of socio-ecological change from an early age. This perspective is in line with the framework of Education for Sustainable Development (ESD) which places schools as incubators of sustainability values, not just transmitters of academic knowledge (Abdullahi et al., 2024).

Fourth, the findings on variable dimensional profiles (with Critical Eco-Digital Thinking and Environmental Responsibility as the relatively weaker dimensions) provide important nuances to 21st-century competency theory. If digital-ecological competence is conceptualized as a spectrum from procedural-normative skills to evaluative-reflective capacity, then this study shows that elementary school students tend to be more advanced at the procedural-normative end and still develop at the evaluative-reflective end. This is in line with the sustainable competency development model proposed by the (Lo, 2024) which emphasizes the importance of pedagogical continuity between primary and secondary education levels in developing ecological critical thinking skills.

Practical Implications

The findings of this study have concrete practical implications and can be immediately implemented at various levels of the education system. At the policy level, the Ministry of Education needs to consider the explicit integration of eco-digital literacy standards into the Pancasila Student Profile, especially in the dimensions of faith and fear of God Almighty and working together. This standard needs to be equipped with measurable indicators that include the four dimensions of eco-digital literacy that have been validated in this study, so that it can be a reference in the development of a curriculum based on Freedom of Learning.

At the school level, the results of this research encourage the development of an integrated and structured eco-digital literacy program, not just inserting environmental content in existing ICT subjects. The program should ideally be designed with gender-responsive pedagogical strategies in mind. For male students, a challenge-based learning approach that links eco-digital literacy to concrete achievement and healthy competition for example, classroom digital carbon footprint reduction challenges, eco-tech innovation competitions, or STEM projects based on real ecological issues are more likely to activate intrinsic motivation that converts competencies into action. For female students, collaborative, reflective, and community-impact-oriented approaches such as group discussions about the socio-ecological implications of technology choices, or environmental-digital leadership

projects tend to resonate more with established values-orientations.

Given that the dimension of Critical Eco-Digital Thinking shows the lowest mean in both gender groups, programs to strengthen ecological-digital critical thinking skills need to receive special attention in curriculum design. Some strategies that may be considered include: (1) the integration of real-world case studies of the environmental impact of digital products and services that students use every day, such as carbon footprint analysis from social media use or video streaming; (2) the application of the Socratic questioning method in techno-environmental discussions to train evaluative skills; (3) the use of interactive digital carbon footprint visualization tools so that abstract impacts become concrete and can be felt; and (4) periodic reflection projects in which students document and analyze their own digital usage patterns from an ecological perspective.

At the teacher level, the results of this study confirm the need for continuous professional development in the field of eco-digital pedagogy. Primary school teachers need to be equipped not only with knowledge of digital technologies, but also an understanding of how to integrate ecological dimensions in everyday digital learning. The training program needs to include scaffolding strategies to develop Critical Eco-Digital Thinking which is still relatively weak, as well as pedagogical differentiation strategies that are responsive to differences in motivation and value orientation between male and female students. Schools are also advised to develop eco-digital ambassador programs that engage students from both gender groups as agents of peer change, leveraging the power of peer modeling that has proven effective in SCT (Bandura, 1986) to reinforce pro-environmental norms organically in the learning community.

The findings on the duration of exposure to paperless correlated with the respondents' profile (45.7% have been exposed for 1–2 years) also provide practical implications: schools that are new to implementing paperless need to provide more intensive pedagogical support in the first year to accelerate the formation of eco-digital literacy, especially in normative dimensions such as Responsible Digital Use which seems to develop more progressively with the duration of exposure. Inter-school mentoring programs, where schools that have been implementing paperless for a long time share good practices with schools that are just starting out, can be an efficient mechanism to accelerate this institutional learning curve.

CONCLUSION

First, eco-digital literacy was found to have a positive and significant effect on sustainable social behavior ($\beta = 0.614$; $t = 12.792$; $p < 0.001$), explaining its 57.7% variance ($R^2 = 0.577$) with a very large effect size ($f^2 = 0.865$) and adequate predictive relevance ($Q^2 = 0.341$), so that H_1 was confirmed. Second, PLS-MGA testing preceded by full-measurement invariance (MICOM) confirmed that gender significantly moderated this relationship ($\Delta\beta = 0.138$; $t = 1.982$; $p = 0.048$), with the effect of eco-digital literacy on sustainable social behavior being stronger among female students ($\beta = 0.681$; $R^2 = 0.624$) of male students ($\beta = 0.543$; $R^2 = 0.520$), so H_2 is also confirmed.These findings suggest that eco-digital literacy is a strong and dominant determinant of sustainable social behavior in the paperless learning ecosystem, and that gender is a meaningful moderator of this relationship rather than a mere demographic covariate. Theoretically, this study validates eco-digital literacy as an integrative construct that bridges digital and ecological competencies at the primary education level, and demonstrates a rigorous methodological approach to test gender moderation through PLS-MGA preceded by MICOM. Practically, the results support the development of a gender-responsive eco-digital literacy curriculum and pedagogical strategies, with particular attention to strengthening students' Critical Eco-Digital Thinking, which emerges as the weakest dimension in both gender groups.

Its cross-sectional design captures the relationship between constructions at a single point in time and cannot establish causality, while its focus on a single country and level of education limits generalization. Future research could use longitudinal design to track how eco-digital literacy and sustainable social behavior evolve along with the accumulation of paperless exposure, extend the model to secondary and tertiary education settings, and analyze the two-dimensional profiles of constructions separately by gender group to more precisely identify where gender differences are most felt.

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