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Readiness Model of Pre-Service Science Teachers for Integrating Education for Sustainable Development (ESD) Based on Green Science: A Structural Equation Modeling Analysis

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ABSTRACT
The presence of Education for Sustainable Development (ESD) is crucial. Therefore, a comprehensive modeling approach is needed, particularly for pre-service teachers as future educators, a group that remains largely underexplored. This study aims to examine a structural model of the formation of the Intention to Integrate ESD among 199 pre-service science teachers at IAIN Sultan Amai Gorontalo. In this readiness model for ESD integration, sustainability literacy is positioned as the primary factor. At the same time, social norms and support, along with institutional support, are treated as contextual factors operating through psychosocial pathways. This study employed a quantitative approach, cross-sectional survey design to examine the structural relationships among variables. Data were analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS) with SmartPLS 4 software. The results indicate that the proposed model explains a substantial proportion of variance in the intention to integrate ESD ($R^2 = 0.744$) and demonstrates adequate predictive relevance ($Q^2 = 0.502$). Institutional support emerges as the strongest predictor ($\beta = 0.670$, $p = 0.000$), while sustainability literacy shows a weaker yet significant effect ($\beta = 0.279$, $p = 0.000$). All constructs meet the required reliability and validity criteria. The findings reveal that, contrary to many theoretical assumptions emphasizing psychosocial mediation pathways, readiness to integrate ESD is predominantly influenced by institutional support rather than by sustainability literacy. In contrast, norms and social support exert their effects through indirect pathways, strengthened by sustainability literacy. This pattern further suggests the need for reformative institutional strategies in delivering ESD to students.

Keywords: *Education for sustainable development, psychosocial, sustainability literacy, SEM-PLS, SmartPLS 4*

INTRODUCTION

Environmental pollution, which has intensified over the past few decades, has had a significant impact on human health and the sustainability of life (Manisalidis et al., 2020; Kumar et al., 2021). This condition demands increased collective awareness and responsibility in maintaining environmental balance. One relevant strategic effort to address this challenge is strengthening activities grounded in Green Science (Medupin et al., 2025; Slobodníková & Tóth, 2025) across sectors, including education. Within this context, the concept of Education for Sustainable Development (ESD) has been developed as an educational approach that integrates environmental, social, and economic dimensions in a sustainable manner.

Various studies indicate that the successful implementation of Education for Sustainable Development (ESD) in education is not determined solely by the introduction of sustainability concepts, but also by how ESD is systematically modeled within pedagogical and institutional frameworks. Several studies emphasize the importance of psychosocial-based approaches, such as

attitudes, self-efficacy, social norms, and pro-environmental behavior, in shaping educators' readiness to integrate ESD into instructional practices. These models generally assume that the internalization of sustainability values develops linearly from affective awareness toward pedagogical intention (Chuvieco et al., 2018; Picado-Valvelde et al., 2022; Shetty, 2024; Adeyemi et al., 2025). However, empirical findings also reveal mixed results, particularly in the context of teacher education, where the influence of psychosocial factors is often inconsistent or fragmented (Saqib et al., 2020; Yli-panula et al., 2023; Yli-panula et al., 2024; Bulut & Oksuzoglu, 2025), thereby highlighting the need for more contextualized and empirically grounded ESD modeling.

Addressing this gap, the present study proposes a readiness model of ESD integration, which conceptualizes pre-service teachers' readiness as a multidimensional construct reflecting their intention to integrate ESD into pedagogical practice. This readiness model is structured by sustainability literacy as a cognitive foundation (Duarte et al., 2023; Mair & Druckman, 2023; Urbaniak & Uzarski, 2023; Mahlaole, 2025; Xiao et al., 2025), with social norms and social support as well as institutional support serving as supporting factors through the mediation of psychosocial constructs in the form of self-efficacy and environmental concern. In contrast to previous studies that tend to regard psychosocial pathways as the primary mediators leading to the intention to integrate ESD (Iqbal & Piwowar-Sulej, 2022; Picado-Valvelde et al., 2022), this model critically examines sustainability literacy as the main factor, complemented by institutional support encompassing curricular policies, academic regulations, and the organizational climate of higher education institutions (Iqbal & Piwowar-Sulej, 2022). The emphasis on sustainability literacy is crucial because ESD integration inherently requires a comprehensive understanding of the principles, objectives, and urgency of the Sustainable Development Goals (SDGs) (Lee & Li, 2025; Ragadhita et al., 2026). For pre-service teachers, pedagogical intention cannot be strongly formed without cognitive clarity regarding what is to be taught, why it is important, and how it is relevant to global and local sustainability challenges. Without adequate sustainability literacy, ESD risks being perceived merely as a policy requirement rather than as a meaningful pedagogical necessity. Thus, the novelty of this study lies in its effort to distinguish the functional boundaries between literacy factors, psychosocial factors, and structural factors in shaping the intention to integrate ESD, particularly within the context of science teacher education in religious higher education institutions.

In line with this framework, this study aims to examine a model of ESD integration intention manifestation among pre-service science teachers at IAIN Sultan Amai Gorontalo using the Structural Equation Modeling–Partial Least Squares (SEM-PLS) approach. Specifically, the study analyzes the direct and indirect roles of Sustainability Literacy, Social Norms and Social Support, and institutional support on the intention to integrate ESD, while considering the mediating roles of Self-Efficacy, Environmental Concern, Pro-Environmental Behavior, and Beliefs in the Usefulness of ESD. The findings of this study are expected to contribute theoretically to the strengthening of a more realistic psychosocial-based ESD model, as well as to provide practical contributions for the development of contextual and applicable policies and curricula in teacher education.

METHODOLOGY

This study employed an explanatory quantitative approach with a cross-sectional survey design to examine the structural relationships among variables within a proposed ESD integration readiness model. The study aims to test predictive relationships and to provide a strategic basis for curriculum design and development by positioning Sustainability Literacy as the primary cognitive foundation and social norms, social support, and institutional support as contextual factors. The model positions Self-Efficacy and Environmental Concern as psychosocial mediators that are expected to promote Pro-Environmental Behavior and, subsequently, shape Beliefs in the

Usefulness of ESD as a rational basis for the intention to integrate ESD. A total of 199 pre-service science teachers participated in this study voluntarily. While the accessible population was larger, participation was limited to those who agreed to complete the questionnaire. Thus, the study employed a non-probability sampling approach. Despite this, the sample size meets the recommended requirements for SEM-PLS analysis, which is robust for small to moderate sample sizes and complex predictive models.

Data were collected through a structured questionnaire designed to specifically measure each latent construct using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree) (De Vellis, 2017), which is widely recommended in behavioral and educational research due to its ability to capture variations in respondents' attitudes and perceptions reliably (Creswell, 2009). Data analysis was conducted using Structural Equation Modeling–Partial Least Squares (SEM-PLS) with the assistance of SmartPLS 4 software (Subhaktiyasa, 2024), as this method is suitable for complex predictive models, does not require strict assumptions of data normality (Hair & Alamer, 2022; Srem-sai et al., 2025), and is effective for use with moderate sample sizes (Becker et al., 2025) in social research (Purwanto & Sudargini, 2021) and educational research (Huang, 2021). The evaluation of the measurement model was conducted by assessing construct reliability and validity. Reliability was assessed using Cronbach's alpha and composite reliability, and convergent validity was evaluated using indicator loadings and average variance extracted (AVE). Discriminant validity was assessed using the heterotrait–monotrait ratio (HTMT), and collinearity was examined using variance inflation factor (VIF) values, following recommended thresholds in PLS-SEM analysis.

The structural model was evaluated by examining path coefficients, the coefficient of determination (R^2), effect sizes (f^2), and predictive relevance (Q^2 predict). The significance of relationships among variables was tested using the bootstrapping procedure, while overall model fit was assessed using the Standardized Root Mean Square Residual (SRMR) index (Subhaktiyasa, 2024; Setiabudi et al., 2025).

RESULT AND DISCUSSION

The conceptual model developed in this study is grounded in the assumption that the successful integration of Education for Sustainable Development (ESD) into instructional practice cannot be separated from the foundation of sustainability literacy possessed by pre-service science teachers. Self-assessed sustainability literacy (A) is positioned as a cognitive (Mair & Druckman, 2023) and reflective prerequisite (Xiao et al., 2025) that shapes how individuals interpret the relationships among humans, the environment, and sustainable development. This literacy does not merely involve mastery of concepts but also functions as a trigger for internal awareness and a value orientation toward environmental issues (Weber et al., 2020; Urbaniak & Uzarski, 2023).

Within this framework, sustainability literacy is assumed to play a role in developing two key aspects: environmental concern (E) and self-efficacy (D) (Alm et al., 2022; Hu et al., 2025). Environmental concern represents the affective dimension reflected in individuals' sensitivity to environmental problems and their moral responsibility to engage in conservation efforts (Nahavandian et al., 2022). Meanwhile, self-efficacy reflects students' personal beliefs in their capacity to contribute meaningfully to sustainable actions (Martinez-Borreguero et al., 2020; Picado-Valvelde et al., 2022). These two constructs are viewed as psychological bridges that connect conceptual understanding with readiness to act.

Nevertheless, the development of environmental concern and self-efficacy does not emerge spontaneously solely from providing sustainability literacy resources. Social norms and social support (B) and institutional support (C) are positioned as contextual factors that may strengthen or weaken the internalization of sustainability values. Social norms shape collective expectations

regarding environmentally friendly behavior (Picado-Valvelde et al., 2022), while institutional support, through policies, facilities, and the academic climate, provides structural legitimacy for ESD practices. The synergy between personal factors and social–institutional factors is a crucial prerequisite for transforming literacy into action (Iqbal & Piwowar-Sulej, 2022).

Furthermore, environmental concern (E) and self-efficacy (D) are expected to lead to the emergence of pro-environmental behavior (F) (Estrada-Araoz et al., 2023; Adeyemi et al., 2025; Berger et al., 2025) as a tangible manifestation of students' sustainability orientation. This behavior is understood not only as individual everyday actions, but also as readiness to integrate sustainability values within the professional context of education. At the same time, experiences of engaging in pro-environmental behavior reinforce beliefs in the usefulness of ESD (G) (Slobodníková & Tóth, 2025), namely the perception that ESD has pedagogical relevance and tangible impacts for learners and society.

Finally, beliefs in the usefulness of ESD, together with these affective and behavioral sustainability experiences, are expected to shape the intention to integrate ESD into teaching and learning practices (H). This intention is presented as an indicator of pre-service teachers' professional readiness to implement ESD in a conscious, systematic, and sustainable manner upon entering the workforce. Thus, this model not only explains the statistical relationships among variables, but also illustrates the developmental process of pre-service teachers who possess awareness, conviction, and commitment to applying the principles of sustainable development in instructional practice.

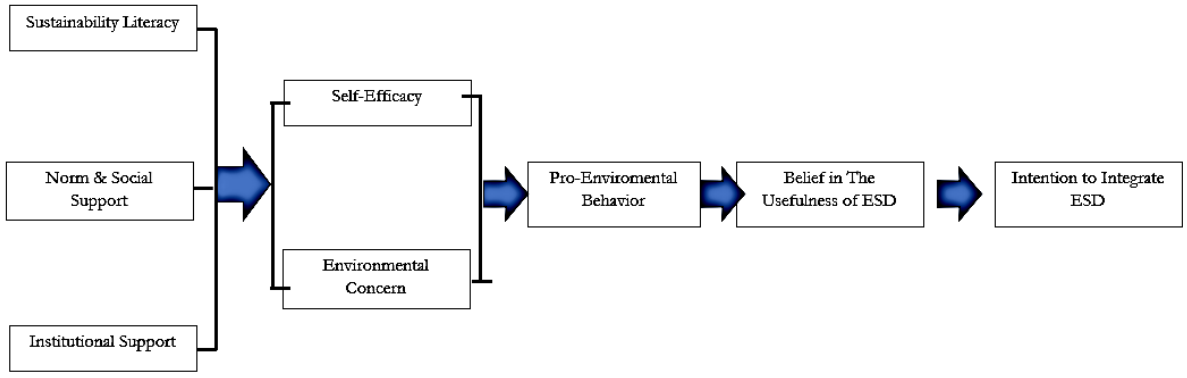

Figure 1. Hypothetical Model of Pre-Service Science Teachers' Readiness for the Integration of Education for Sustainable Development (ESD)

The reliability of the measurement model was evaluated using Cronbach's alpha and composite reliability indices (ϱc and ϱa) to assess the internal consistency of reflective constructs. As presented in Table 1, the results indicate that reflective constructs demonstrate satisfactory to high reliability, meeting the recommended thresholds for PLS-SEM analysis (Cronbach's Alpha>0,5; pc>0,7) (De Vellis, 2017; J. F. J. Hair et al., 2017).

Table 1. Reliability of the Measurement Model

Construct	Cronbach's Alpha	Composite Reliability (ϱc)	Composite Reliability (ϱa)
A – Sustainability Literacy	0.819	0.874	0.820
B – Norms & Social Support	0.873	0.908	0.877
C – Institutional Support	1.000	1.000	1.000
D – Self-Efficacy	0.879	0.912	0.882

Construct	Cronbach's Alpha	Composite Reliability (ρc)	Composite Reliability (ρa)
E – Environmental Concern	0.884	0.915	0.884
F – Pro-environmental Behavior	1.000	1.000	1.000
G – Belief in the Usefulness of ESD	0.900	0.926	0.903
H – Intention to Integrate ESD	0.899	0.925	0.899

Convergent validity was assessed by examining indicator loadings and the Average Variance Extracted (AVE) for each reflective construct. In PLS-SEM, convergent validity is considered adequate when indicator loadings are generally above 0.50 and statistically significant, and when AVE values exceed the recommended threshold of 0.50 (J. F. J. Hair et al., 2022). The results indicate that the majority of indicators demonstrate satisfactory outer loadings and statistical significance, supporting adequate convergent validity of the measurement model.

Table 2. Outer Loadings and Average Variant Extract (AVE) of Reflective Construct

Construct	AVE	Indicator	Outer Loading
Sustainability Literacy (A)	0.581	A1; A2; A3; A4; A5	0.750; 0.803; 0.767; 0.754; 0.735
Norms & Social Support (B)	0.665	B1; B2; B3; B4; B5	0.779; 0.776; 0.889; 0.821; 0.807
Self-Efficacy (D)	0.674	D1; D2; D3; D4; D5	0.829; 0.809; 0.803; 0.817; 0.846
Environmental Concern (E)	0.684	E1; E2; E3; E4; E5	0.814; 0.784; 0.862; 0.846; 0.827
Belief in the Usefulness of ESD (G)	0.714	G1; G2; G3; G4; G5	0.868; 0.859; 0.849; 0.867; 0.779
Intention to Integrate ESD (H)	0.712	H1; H2; H3; H4; H5	0.835; 0.870; 0.845; 0.832; 0.835

Institutional Support (C) and Pro-environmental Behavior (F) were specified as formative. Therefore, convergent validity was not evaluated using AVE or traditional loading criteria. Instead, the relevance and contribution of individual indicators were considered, acknowledging that formative indicators are not expected to be highly correlated or interchangeable.

Discriminant validity was assessed using the HTMT criterion. The majority of HTMT values were below the recommended threshold of 0.85 (or 0.90 in conceptually related constructs), indicating acceptable discriminant validity among the reflective constructs. The results show that the majority of HTMT values fall below the recommended threshold, indicating adequate discriminant validity among the reflective constructs (J. F. J. Hair et al., 2022). Consistent with PLS-SEM guidelines, HTMT inference was not emphasized due to the moderate sample size and the predictive orientation of the PLS-SEM approach employed (Sarstedt et al., 2016; J. F. Hair et al., 2019; Shmueli et al., 2019; Amar et al., 2024; Li & Lay, 2024). Moreover, HTMT was not evaluated for formative constructs, as indicator collinearity rather than discriminant validity is the primary concern in formative measurement models (Setiabudi et al., 2025).

Table 3. Heterotrait-Monotrait Ratio (HTMT) of Reflective Construct

Construct	HTMT
B–A	0.673
D–A	0.876
D–B	0.744
E–A	0.750
E–B	0.787
E–D	0.763
G–A	0.656
G–B	0.687
G–D	0.646
G–E	0.816
H–A	0.766
H–B	0.693
H–D	0.785
H–E	0.774
H–G	0.861

Collinearity among indicators in the measurement model was examined using variance inflation factor (VIF) values to ensure that no indicator exhibited excessive overlap with others within the same construct. The results show that all outer VIF values are below the conservative threshold of 3.3 (J. F. J. Hair et al., 2022), with most indicators displaying VIF values close to 1. This finding indicates the absence of multicollinearity at the indicator level and suggests that each item contributes unique information to its respective construct.

Table 4. Collinearity Statistics of the Measurement Model (Outer Model) Using VIF

Construct	Indicator	VIF
A – Sustainability Literacy	A1; A2; A3; A4; A5	1.587; 2.020; 1.862; 1.582; 1.489
B – Norms & Social Support	B1; B2; B3; B4; B5	2.114; 1.958; 3.236; 2.038; 2.020
C – Institutional Support	C1; C2; C3; C4; C5	2.641; 2.442; 2.877; 2.134; 2.375
D – Self-Efficacy	D1; D2; D3; D4; D5	2.335; 2.243; 1.934; 2.325; 2.440
E – Environmental Concern	E1; E2; E3; E4; E5	2.101; 1.835; 2.580; 2.508; 2.110
F – Pro-environmental Behavior	F1; F2; F3; F4	1.693; 1.423; 1.792; 1.669
G – Belief in the Usefulness of ESD	G1; G2; G3; G4; G5	2.959; 2.851; 2.616; 2.655; 2.018
H – Intention to Integrate ESD	H1; H2; H3; H4; H5	2.253; 2.920; 2.541; 2.300; 2.352

The structural model demonstrates substantial explanatory power, with the intention to integrate ESD (H) showing a high coefficient of determination ($R^2 = 0.744$), indicating that the model explains 74.4% of the variance. In addition, the model's predictive relevance is supported by a positive Q^2 value ($Q^2 = 0.502$), indicating adequate out-of-sample predictive capability (J. F.

J. Hair et al., 2022; Mehmetoglu & Venturini, 2021; J. F. J. Hair et al., 2022; Chew et al., 2025). Model fit was assessed using the standardized root mean square residual (SRMR). The bootstrap mean SRMR values for both the saturated model (0.067) and the estimated model (0.069) are below the recommended threshold of 0.10, indicating an acceptable overall model fit (Vinzi et al., 2010; J. F. J. Hair et al., 2022; Sarstedt et al., 2025). These results suggest that the estimated model demonstrates a stable approximation of the observed correlations.

The results of the structural path analysis (Table 5) indicate the significance of direct effects among the model's variables. A path is considered statistically supported when the t-value exceeds the 1.96 critical value, and the p-value is below 0.05, indicating significance at the 5% level. In addition, positive standardized path coefficients (β) indicate a positive directional relationship, meaning that an increase in the predictor variable corresponds to an increase in the outcome variable (Setiabudi et al., 2025).

Table 5. Results of Structural Path Analysis

Path	β	t	P	Decision
A → D	0.497	7.184	0.000	Supported
A → E	0.368	4.655	0.000	Supported
A → F	0.053	0.625	0.532	Not supported
A → F (indirect effect)	0.287	4.842	0.000	Supported
A → G	0.050	0.581	0.561	Not supported
A → G (indirect effect)	0.198	2.860	0.004	Supported
A → H	0.279	3.864	0.000	Supported
B → D	0.254	3.385	0.001	Supported
B → E	0.514	5.977	0.000	Supported
B → F	-0.076	0.771	0.441	Not supported
B → F (indirect effect)	0.354	4.883	0.000	Supported
B → G	0.059	0.680	0.497	Not supported
B → G (indirect effect)	0.250	3.125	0.002	Supported
B → H	0.057	0.640	0.522	Not supported
B → H (indirect effect)	0.207	2.621	0.009	Supported
C → D	0.069	0.871	0.384	Not supported
C → E	-0.011	0.108	0.914	Not supported
C → F	-0.015	0.242	0.808	Not supported
C → G	0.025	0.275	0.783	Not supported
C → H	0.670	9.382	0.000	Supported
D → F	0.016	1.225	0.221	Not supported
D → G	-0.100	1.161	0.246	Not supported
D → H	0.210	2.112	0.035	Supported
E → F	0.636	7.934	0.000	Supported
E → G	0.340	2.756	0.006	Supported

Path	β	t	P	Decision
E → H	-0.152	1.367	0.172	Not supported
E → H (indirect effect)	0.475	4.751	0.000	Supported
F → G	0.361	2,935	0.003	Supported
F → H	0.382	3.441	0.001	Supported
G → H	0.407	4.247	0.000	Supported

The structural path analysis reveals that institutional support (C) has the strongest positive effect on intention to integrate ESD (β = 0.670, p = 0.000), followed by sustainability literacy (A) (β = 0.279, p = 0.000). In contrast, Norms & Social Support (B) are not statistically significant. However, several psychosocial pathways show significant relationships, particularly from variable Norms & Social Support (B) to self-efficacy (D) and environmental concern (E) (Hogan & O'flaherty, 2021). However, these influences do not extend to higher-order outcomes such as pro-environmental behavior (F), belief in the usefulness of ESD (G), and intention to integrate ESD (H). These findings indicate that the formation of ESD integration intention is not primarily driven by affective or behavioral mediation, but rather by structural and cognitive factors (Duarte et al., 2023). In this context, pedagogical intention appears to be driven more by structural readiness than by internalized psychosocial dispositions. Although students may perceive social support, the decision to actually integrate ESD into instructional practices remains a professional judgment that is more strongly shaped by structural and cognitive factors than by normative pressure.

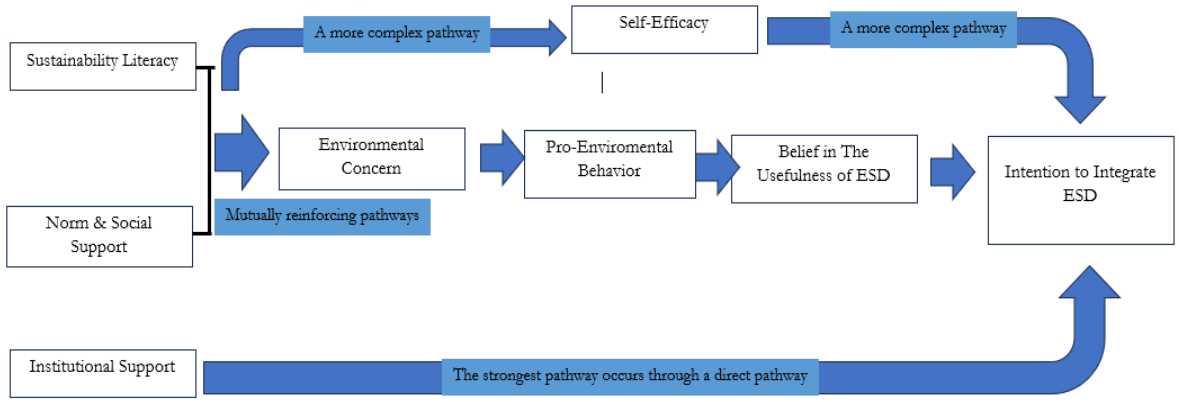

Figure 2. Proposed Model of Pre-Service Science Teachers' Readiness for the Integration of Education for Sustainable Development (ESD)

This pattern is consistent with findings from previous studies indicating that, even within university settings where sustainability culture and SDGs-oriented agendas are explicitly promoted, many students tend to interpret such orientations as organizational characteristics or as attributes of particular institutional initiatives rather than as enduring personal or professional commitments. Within this context, engagement with sustainability is often driven by short-term participation or symbolic alignment with environmentally oriented student organizations, rather than by a long-term pedagogical orientation. Consequently, students may acknowledge the value and relevance of ESD at the organizational level, or they may be willing to externalize responsibility for its implementation to the broader organizational sphere; however, they tend to exhibit a limited intention to apply ESD only within the boundaries of these implicit organizational domains, without a stronger inclination to internalize it as an individual value reflecting their readiness to teach it to others on a personal and professional basis (Holst et al., 2025).

Environmental concern (E) significantly predicts pro-environmental behavior (F), indicating that students who hold positive environmental attitudes are more likely to engage in environmentally responsible actions. Furthermore, pro-environmental behavior (F) significantly influences belief in the usefulness of ESD (G), which in turn significantly predicts intention to integrate ESD (H). These findings reveal a sequential mediation pathway in which psychosocial factors indirectly influence intention through behavioral mechanisms. Notably, the relationships among these variables weaken or disappear when key mediators (F or G) are removed, indicating full mediation within the model.

Self-efficacy (D) demonstrates a significant indirect effect on the intention to integrate ESD, indicating its influence on intention through alternative pathways within the model. However, it does not exhibit a significant relationship with pro-environmental behavior or belief in the usefulness of ESD, either directly or indirectly through the hypothesized mediating pathways. It suggests that, within the present model, self-efficacy does not operate through the expected behavioral and cognitive mediation mechanisms, but instead contributes to intention formation via other structural or contextual pathways.

Sustainability literacy, social norms, and support, when considered independently, may contribute to the development of self-efficacy and environmental concern. However, these factors do not necessarily translate directly into pro-environmental behavior, belief in the usefulness of ESD, or intention to integrate ESD, despite demonstrating significant indirect effects within the model. It indicates that there is a mutually reinforcing relationship among these variables, where they collectively act as supportive elements that enhance the intention to integrate ESD via psychosocial pathways (Chen et al., 2024; Eilam, 2025).

Interestingly, institutional support directly predicts intention to integrate ESD without exerting significant effects on self-awareness, environmental concern, pro-environmental behavior, or ESD-related beliefs. This finding suggests that institutional structures may compel pedagogical intention even in the absence of internalized environmental values. This finding underscores that institutional policies, curriculum frameworks, available facilities, and the overall institutional climate can shape pre-service teachers' pedagogical intentions (Tassone et al., 2022) without directly engaging their psychosocial domains, but rather through institutional obligations and academic requirements that must be fulfilled as part of their responsibilities to complete their studies and meet graduation criteria.

This finding demonstrates that institutional support is the most critical determinant of pre-service teachers' intention to integrate ESD. Rather than directly targeting students' internal awareness, institutional mechanisms structure learning experiences and require students to engage with sustainability-related content, thereby gradually fostering environmental concern through repeated exposure and academic reinforcement (Zhang & Cao, 2025). Nevertheless, this role remains essential, as institutional support provides the foundational conditions for ensuring that sustainability education is consistently implemented within teacher preparation programs. In this sense, although it may initially operate at a compliance level, institutional support still plays a central role in guiding students toward greater familiarity and the gradual internalization of sustainability-oriented practices. The implementation of ESD from an institutional perspective can be strategically strengthened through curriculum design that emphasizes academic discipline, clear learning requirements, and structured sustainability-related competencies. In this context, institutional efforts may be more effective when they focus on formal curricular integration and performance-based academic expectations rather than relying solely on affective or counseling-based approaches. Such a structured approach ensures that students are consistently exposed to sustainability concepts as part of their academic responsibilities, thereby fostering both compliance and the internalization of ESD principles.

However, this does not imply that psychosocial pathways are ineffective. Although social norms and social support do not directly influence the intention to integrate ESD, they may still contribute to intention formation when mediated through appropriate psychosocial mechanisms. In this regard, a potential strategy is to strengthen student engagement through environmentally focused student organizations and institutional initiatives to establish dedicated organizations that foster students' self-confidence to engage actively in environmental activities. Within such environments, intention to integrate ESD may be more effectively developed compared to direct institutional socialization alone, as indicated by the findings that institutional support exerts the strongest direct effect but does not significantly operate through psychosocial pathways.

Furthermore, regarding norms and social support, its effectiveness depends on the availability of solid sustainability literacy that is not only theoretical but also practice-oriented. This can be addressed through institutional curriculum improvement that emphasizes science literacy aligned with PISA objectives and the Sustainable Development Goals (SDGs), thereby integrating conceptual understanding with real-world application (Karvonen et al., 2023).

Strengthening the affective and value-based foundations of ESD in science teacher education is essential to ensure that future educators not only intend to integrate ESD for academic purposes but are also intrinsically motivated to protect the environment and promote the well-being of humanity at a global scale. This finding offers a novel contribution to the ESD literature by emphasizing the role of institutional support from a different perspective, which has predominantly focused on institutional socialization as a means of fostering students' awareness and intention to implement ESD in learning. Rather than relying solely on direct socialization, a more effective approach may involve strengthening disciplinary structures and psychosocial awareness through student organizations and institutional units specifically designed to foster students' engagement with SDGs at both cognitive and affective levels.

However, contrary to the initial hypothesis, sustainability literacy does not emerge as the primary determinant; rather, institutional support plays a more dominant role. Sustainability literacy enables social norms and social support to exert significant indirect effects on the intention to integrate ESD by strengthening psychosocial pathways, particularly through their influence on self-efficacy and environmental concern. In addition to exerting a direct influence on the intention to integrate ESD, institutional support also contributes substantially to reinforcing intention formation by strengthening social norms and social support within psychosocial pathways. These results also open important sustainability-oriented research opportunities to further examine the role of sustainability literacy in strengthening institutional support through mediating variables related to students' awareness developed beyond formal learning contexts, particularly through community organizations, television media, social media, and other informal educational channels. The inclusion of such additional data may further reinforce the position of sustainability literacy as a fundamental foundation for fostering a scientifically literate society that is aware of Sustainable Development Goals (SDGs) issues.

Furthermore, more robust investigations into psychosocial pathways are required to explain better the roles of social norms and social support, particularly in relation to the complex and sometimes inconsistent relationships observed between self-efficacy and pro-environmental behavior or beliefs about the usefulness of ESD across different pathways. These inconsistencies may indicate that self-efficacy is mediated or moderated by other contextual factors, such as peer influence or learning environments. They also suggest that individuals' confidence in engaging in pro-environmental behavior does not always translate directly into stronger beliefs about the usefulness of ESD. These highlight the need for more integrative and context-sensitive models. This study has several limitations that warrant consideration. Sustainability literacy was measured through self-assessment, and the cross-sectional design limits the ability to capture developmental changes in psychosocial constructs over time, while the localized sample context constrains the generalizability of the findings.

CONCLUSION

In conclusion, the results of the Partial Least Squares Structural Equation Modeling analysis reveal that Institutional Support is the most dominant predictor of pre-service teachers' intention to integrate Education for Sustainable Development (ESD), with the strongest direct effect on intention (β = 0,670, p = 0.000). Sustainability literacy does not emerge as the primary direct predictor of intention; however, it plays a significant supporting role within the model by strengthening psychosocial pathways. In particular, sustainability literacy significantly contributes to self-efficacy (β = 0.497) and environmental concern (β = 0.368), which, in turn, influence pro-environmental behavior and belief formation, ultimately shaping the intention to integrate ESD. Social norms and social support do not show a significant direct effect on ESD integration intention (p > 0.05). However, they exert an indirect effect through psychosocial pathways, suggesting a mediated rather than a direct structural relationship. Overall, the model explains a substantial proportion of variance in ESD integration intention (R^2 = 0.744), highlighting a dual mechanism in which institutional support acts as the primary driver, while sustainability literacy functions as a reinforcing factor that enhances psychosocial development and indirect behavioral pathways.

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