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PREDICTING SCIENCE TEACHERS' PEDAGOGICAL APPROACHES TO SUSTAINABLE DEVELOPMENT: THE ROLE OF SELF-EFFICACY, ATTITUDE, KNOWLEDGE AND SCHOOL SUPPORT

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ABSTRACT

This study aimed to identify the most significant predictors of science teachers' pedagogical approach to sustainable development (SD) by examining the roles of ESD teaching self-efficacy, attitude towards SD, knowledge about SD, and school support. A total of 896 in-service primary science teachers across Malaysia participated in the study through a structured online questionnaire. The data were analysed using structural equation modelling (SEM) via AMOS version 26. Results showed that ESD teaching self-efficacy was the strongest predictor of teachers' pedagogical approach to SD, followed by school support, while attitude and knowledge were not statistically significant predictors. The final model accounted for 25% of the variance in pedagogical approach. These findings highlight the need to enhance teachers' confidence and provide strong institutional support to promote sustainability-oriented teaching practices. The study offers practical implications for teacher education and policymaking by identifying key factors such as self-efficacy and school support that can enhance the implementation of Education for Sustainable Development in primary science classrooms.

Keywords: *Education for Sustainable Development (ESD), self-efficacy, knowledge, attitude, school support.*

INTRODUCTION

Education for Sustainable Development (ESD) aims to help learners develop the knowledge, values, and skills necessary to address complex environmental, social, and economic issues. A key part of ESD is changing teaching practices from traditional, content-focused and teacher-centred methods to more student-centred and action-based approaches. Achieving this change involves more than just updating the curriculum; it also requires teachers to change how they understand and apply sustainability in their teaching.

Although ESD has gained global traction, evidence suggests that its implementation in classrooms, particularly at the primary level, remains limited and uneven. Many science teachers continue to prioritise factual knowledge and textbook-based instruction over approaches that foster systems thinking, critical reflection, and real-world engagement (UNESCO, 2020; Vong & Sidhu, 2021). Even when teachers possess positive attitudes towards sustainability, they often face structural constraints such as rigid syllabi, a lack of professional support, and assessment-driven pressures, that hinder pedagogical transformation (Boeve-de Pauw et al., 2022; Yang et al., 2024).

Numerous studies have explored teacher preparedness for ESD implementation, yet most focus on pre-service teachers or broad educational contexts rather than science educators in primary schools. In Malaysia, although science is a key subject at the primary level, there is limited empirical evidence on

how psychological and contextual factors affect in-service teachers' approaches to teaching sustainability. Furthermore, while previous studies have examined relationships among individual variables such as self-efficacy, attitudes, or school conditions, few have investigated their combined predictive power on pedagogical approaches for SD within a single model.

Addressing this gap, the present study examines which factors most significantly predict primary science teachers' pedagogical approach to sustainable development. Specifically, it investigates how four key factors (ESD teaching self-efficacy, attitudes towards sustainable development, knowledge of sustainable development, and school support) contribute to variations in how teachers implement ESD-related pedagogical strategies. These predictors are conceptualised through four theoretical lenses: Social Cognitive Theory (SCT), the Theory of Planned Behaviour (TPB), Self-Determination Theory (SDT), and Expectancy-Value Theory (EVT), which together provide an integrated understanding of how individual and contextual factors influence sustainability-oriented teaching.

By identifying the key drivers of sustainable pedagogical practices, this study offers valuable insights for designing targeted professional development programmes that enhance teachers' self-efficacy and capacity to teach ESD. It also contributes evidence to inform school leadership and policy reforms aimed at fostering supportive environments for sustainability education. Additionally, the findings hold implications for revising national curriculum and teacher education frameworks in Malaysia to more effectively embed ESD competencies within primary science education.

Objective of the Study

To determine which among ESD teaching self-efficacy, attitudes towards sustainable development, knowledge of sustainable development, and school support most strongly predict science teachers' pedagogical approaches to sustainable development.

LITERATURE REVIEW

Theoretical Frameworks Underpinning the Pedagogical Approaches for SD

This study is underpinned by four complementary theories that, together, illuminate how individual beliefs and contextual factors shape teachers' pedagogical approach to sustainable development (SD).

Social Cognitive Theory. According to Social Cognitive Theory (Bandura, 1997), perceived capability plays a vital role in behaviour. Teachers who believe in their ability to deliver ESD effectively are more inclined to experiment with innovative, learner-focused strategies. Therefore, consistent with SCT, we hypothesised that ESD teaching self-efficacy would be a significant positive predictor of teachers' pedagogical approach to sustainable development.

Theory of Planned Behaviour (TPB). TPB (Ajzen, 1991) addresses intention**:** favourable attitudes toward SD, coupled with perceived behavioural control, translate into a stronger intention to teach for sustainability. Drawing on Ajzen's Theory of Planned Behaviour (1991), which emphasises that behavioural intentions shaped by control beliefs predict actions, this study posits that positive attitudes toward SD can influence how teachers implement sustainable pedagogical practices, especially when reinforced by strong self-efficacy. In this model, ESD teaching self-efficacy serves as a proxy for perceived behavioural control, strengthening the link between attitude and practice.

Self-Determination Theory (SDT). SDT (Deci & Ryan, 2000) highlights motivation**:** when school environments support autonomy, competence, and relatedness, teachers are more intrinsically motivated to incorporate ESD. Thus, we hypothesised that greater school support would positively predict teachers' pedagogical approach to SD.

Expectancy-Value Theory (EVT). EVT (Eccles & Wigfield, 2020) adds the dimension of utility and cost: teachers judge whether the expected benefits of adopting SD pedagogy outweigh the effort required, influencing their commitment to change. From an EVT perspective, we hypothesised that

teachers' knowledge about SD (representing their understanding of the value and utility of SD content) would be a significant predictor of their pedagogical approach to SD.

Together, these frameworks form an integrated explanatory lens: SCT clarifies teachers' perceived capability, TPB elucidates their intention, SDT accounts for contextual support and intrinsic motivation, and EVT captures cost-benefit appraisals. By combining these perspectives, the study provides a more comprehensive explanation of how psychological and environmental factors converge to shape sustainable teaching practices.

Conceptualizing ESD in Science Education

Education for Sustainable Development (ESD) takes a comprehensive approach to preparing learners to take an active role in shaping a fairer and more sustainable world. According to UNESCO (2017, 2020), ESD aims to develop the essential knowledge, competencies, values, and attitudes needed to tackle pressing global issues, including climate change, poverty, and inequality. It emphasises lifelong learning, interdisciplinarity, and participatory pedagogies that enable students to reflect critically, act responsibly, and envision futures alternatively.

Contemporary scholarship highlights that ESD is not merely about transferring environmental facts, but rather about transforming how learners think, act, and relate to the world (Sterling, 2011; Vare & Scott, 2007). This transformative orientation demands changes in educational philosophy, pedagogy, and institutional culture. It positions education as a process of enabling agency and critical awareness, which are essential for engaging with complex sustainability issues.

In this study, ESD is situated within primary science education as a context where sustainability concepts can be meaningfully integrated into teaching practice. Through fostering inquiry, systems thinking, and socio-scientific reasoning, science classrooms offer a natural platform for ESD implementation. However, achieving this integration depends not only on curriculum content but also on teachers' confidence, attitudes, knowledge, and the support they receive in their professional environments.

Pedagogical Approaches for Sustainable Development

A pedagogical approach to sustainable development encompasses teaching strategies that actively engage learners in understanding and addressing real-world sustainability issues. In the context of ESD, three key dimensions are often highlighted: real-world learning, critical learning, and experiential learning (UNESCO, 2020; Rieckmann, 2018).

Real-world learning involves linking educational content to actual sustainability challenges at both local and global levels. This approach encourages students to apply scientific knowledge in meaningful, real-life situations. For example, science lessons can explore topics such as energy use, waste management, or biodiversity through inquiry into students' communities.

Critical learning cultivates learners' capacity to interrogate beliefs, assess information critically, and reflect on underlying values and decision-making frameworks. This dimension cultivates critical thinking and ethical reasoning, which are essential for responsible citizenship and transformative action. In science education, critical learning might involve analysing the environmental impacts of human activities or exploring multiple perspectives on environmental justice.

Experiential learning highlights hands-on involvement where students gain understanding through direct action, reflection, and collaborative problem-solving experiences. This approach supports the development of competencies such as collaboration, adaptability, and innovation (Barth et al., 2019). In practice, this may include project-based learning, outdoor investigations, or sustainability campaigns within the school environment.

Together, these dimensions support a pedagogy that moves beyond rote learning toward one that empowers students to think and act sustainably. In this study, the pedagogical approach for SD is examined as a multidimensional construct, assessing how science teachers implement real-world,

critical, and experiential learning strategies in their classrooms. In exploring the factors influencing science teachers' pedagogical approaches to sustainable development (SD) in science education, it is essential to consider variables such as self-efficacy, attitudes towards SD, knowledge of SD, and school support. Recent studies provide insights into how these factors interplay to shape teaching practices.

ESD Teaching Self-Efficacy

Recent research has increasingly explored how teachers' self-efficacy influences their instructional practices, particularly in sustainability education. Findings consistently show that educators with higher self-efficacy are more capable of integrating sustainability into their teaching. For example, Sari and Kiray (2021) identified a strong link between high self-efficacy and the effective application of sustainability-focused instruction. Likewise, Wulff and Lehti (2020) highlighted that pre-service teachers with greater confidence in their teaching abilities tend to develop stronger sustainability-related competencies. Teachers' confidence in their capacity to carry out specific instructional tasks also plays a critical role in the adoption of innovative teaching strategies. Supporting this, a study by Mohd Shahali and Halim (2024) revealed that science teachers' self-efficacy influenced their integrated STEM teaching both directly and indirectly, through attitudes toward interdisciplinary approaches. These results underscore self-efficacy as a vital factor in enabling progressive and cross-disciplinary teaching methods.

Attitudes Towards Sustainable Development

Teachers' attitudes towards SD play a crucial role in their willingness to incorporate sustainability concepts into their teaching. Recent research by Abowardah et al. (2024) indicates a strong positive inclination among educators to integrate environmental sustainability projects and dynamic sustainability dimensions into the curriculum, highlighting their enthusiasm for such approaches. Furthermore, a study by Letina and Dikovic (2024), specifically examining future teachers' knowledge, attitudes, and practices regarding Sustainable Development Goals, found a significant correlation between positive attitudes and practical actions. This underscores that positive attitudes towards innovative teaching approaches, including those related to sustainability, are essential for effective implementation, a point further supported by Mohd Shahali and Halim (2024), who found that constructivist conceptions of teaching and learning on teaching practices are fully mediated by attitudes towards integrated STEM teaching.

Knowledge about Sustainable Development

Teacher readiness for sustainability education remains inconsistent, particularly among pre-service and in-service educators. In a qualitative investigation, Koskela and Kärkkäinen (2021) noted that many Finnish pre-service teachers demonstrated a limited grasp of sustainable development's core elements, often placing greater emphasis on its social dimension over environmental or economic aspects. They emphasised that collaborative discussions among educators from diverse backgrounds can foster a more comprehensive grasp of SD.

However, focusing solely on pre-service perspectives overlooks the realities faced by in-service elementary science teachers. These educators often encounter institutional, curricular, and time-related constraints that hinder the integration of Education for Sustainable Development (ESD) (Birdsall, 2016; Foley, 2020). Pressures from standardised testing frequently led teachers to prioritise core subject content over interdisciplinary approaches, leaving little room for sustainability pedagogy (Pamuk et al., 2022). While many teachers are aware of sustainability principles, they often lack the pedagogical strategies and support necessary for effective implementation.

International studies echo these challenges. In Finland, Wolff et al. (2017) reported that despite high academic performance, sustainability education was inconsistently delivered due to its optional status in teacher training. Teachers called for strategic integration of SD concepts, not additional policies. Similar findings emerged in Germany and Romania, where educators highlighted the need for practical support, time allocation, and curriculum flexibility (Pamuk et al., 2022; Burmeister et al., 2013; Cebrên et al., 2019). These findings underscore the persistent gap between sustainability awareness and classroom practice, particularly in science education.

School Support in ESD Implementation

Institutional support, including administrative and collegial support, significantly influences the successful implementation of ESD. Shahali and Halim (2024) highlighted the significance of contextual influences such as leadership backing and peer collaboration in shaping how teachers approach their instructional practices, particularly within integrated STEM and ESD settings. Supportive school environments facilitate the adoption of integrated STEM teaching practices, which can be extended to ESD implementation.

Collectively, these studies underscore the multifaceted nature of implementing sustainable pedagogical approaches in science education. Enhancing teachers' self-efficacy, fostering positive attitudes towards SD, deepening their knowledge of sustainability, and ensuring robust school support systems are crucial for the successful integration of ESD into science curricula (Pamuk et al., 2022).

METHODOLOGY

Research Design

This research adopted a non-experimental, quantitative design, specifically utilising a causal-correlational approach. The purpose was to examine how four independent factors, ESD teaching self-efficacy, attitudes towards sustainable development (SD), knowledge about SD, and school support, contribute to predicting the pedagogical approaches used by primary science teachers in implementing SD. This design enabled the investigation of potential relationships and identification of key predictors without the need for variable manipulation.

Participants and Sampling

A stratified random sampling method was employed to obtain a representative group of science teachers from different regions throughout Malaysia. The sampling frame consisted of 38,173 primary science teachers, as listed by the Malaysian Ministry of Education. Based on recommended sample size calculations for structural equation modelling (SEM), an initial target of 1,004 responses was set to account for possible non-responses and data exclusion. This target was established to meet the recommended sample size for Structural Equation Modelling, typically requiring a minimum of 10-20 participants per estimated parameter to ensure robust model estimation and generalizability (e.g., Kline, 2016). After data cleaning, a total of 896 valid responses were retained and used for analysis.

Ethical Considerations

Ethical approval for this study was secured from the Educational Planning and Research Division (EPRD), the University of Malaya Research Ethics Committee (UMREC), and all relevant State Education Departments (JPN). Participation was entirely voluntary, with participants fully informed of the study's objectives, confidentiality measures, and their freedom to withdraw at any stage. Informed consent was obtained electronically before data collection.

Data Collection Instrument

The survey instrument comprised five different questionnaires, with the research instruments adapted for use in this study. The survey instrument was structured into six sections: Section A (Demographic Information), Section B (ESD Teaching Self-efficacy), Section C (Attitude towards SD), Section D (Knowledge about SD), Section E (School Support in ESD Implementation) and Section F (Pedagogical Approach to SD). The final version of the research instrument was developed after revisions were made based on the results of the Exploratory Factor Analysis (EFA), ensuring the instrument's validity. The finalised instrument, as shown in Table 2, is named SEAKS-P (Self-Efficacy, Attitude, Knowledge and School Support in Pedagogical Approach for Sustainable Development Questionnaire), representing the core dimensions of the study.

All six variables in the instrument were measured using a standardised seven-point Likert scale for consistency. Higher scores (7) reflected a stronger endorsement or presence of the construct, while lower scores (1) indicated a weaker endorsement. For the first four constructs, (i) ESD Teaching Self-Efficacy, (ii) Attitude towards Sustainable Development (SD), (iii) Knowledge about SD, and (iv) School

Support, a seven-point agreement scale was used: 1 = Strongly Disagree to 7 = Strongly Agree. In contrast, the Pedagogical Approach to SD was assessed using a frequency-based seven-point scale, ranging from 1 = Never to 7 = Always.

Table 1.
Details of Variables, Sources, Dimension, Item Distribution and Reliability in SEAKS-P

Variables	Sources (adapted from)	Dimension	Number of items	Cronbach's Alpha Value
ESD Teaching Self-efficacy	Stant, 2016	Personal Teaching Efficacy Scale (PTE)	12	0.810
		Teaching Outcome Expectancy Scale (TOE)	7	
Attitude towards SD	Biasutti and Frate (2017)	Environment	5	0.810
		Economy	5	
		Society	5	
		Education	5	
Knowledge about SD	Aye et al. (2019)		13	0.896
School Support in ESD Implementation	Amabile et al. (1996)	School head support	5	0.961
		Science panel head support	5	
		Colleague support	5	
Pedagogical Approach to SD	Said et.al (2021)	Real-world learning	4	0.941
		Critical Problem Solving	4	
		Experiential learning	3	
		Total Item	78	

Data Analysis Procedure

The data were analysed using Structural Equation Modelling (SEM) with the support of AMOS Version 26 software. Before testing the hypothesised relationships, a rigorous data screening process was carried out. Responses with excessive missing values, patterned answering, or outliers were excluded, resulting in a final sample of 896 valid cases.

Measurement Model Validation. In the initial stage of analysis, Confirmatory Factor Analysis (CFA) was performed to verify the measurement model. This process evaluated both the validity and reliability of the latent constructs, including ESD teaching self-efficacy, attitudes towards sustainable development, knowledge of SD, school support, and the pedagogical approach to SD. Items with standardised factor loadings below 0.50 were removed to improve model fit and ensure unidimensionality. Internal consistency was confirmed with Cronbach's alpha values exceeding 0.80 for all constructs (Table 1).

Structural Model Testing. After establishing measurement validity, the structural model was developed to examine the direct effects of self-efficacy, attitudes, knowledge and school support on the pedagogical approach to SD. The model was specified based on theoretical assumptions and empirical findings. Standardised path coefficients (β) were estimated to determine the relative predictive strength of each construct.

Model Fit Evaluation. The overall fit of the structural model was assessed using several standard fit indices widely used in Structural Equation Modelling (SEM). The model met all recommended thresholds, indicating an acceptable fit to the data:

- Chi-square to degrees of freedom ratio (χ^2/df) = 1.997, which falls below the acceptable cut-off of 3.00
- Comparative Fit Index (CFI) = 0.939, exceeding the minimum acceptable value of 0.90
- Tucker-Lewis Index (TLI) = 0.937, also above the suggested threshold of 0.90
- Root Mean Square Error of Approximation (RMSEA) = 0.033, within the acceptable limit of 0.08

These indicators collectively confirmed that the structural model had a good fit, providing strong support for the hypothesised relationships between the constructs.

RESULTS

This section presents (a) the descriptive statistics for all study variables and (b) the results of the structural equation model that identifies the strongest predictors of science teachers' pedagogical approach to sustainable development (SD).

Descriptive Statistics. Table 2 summarises the mean (M) and standard deviation (SD) for each construct. Teachers reported the highest scores for attitudes towards SD (M = 5.51, SD = 0.72) and knowledge about SD (M = 5.49, SD = 0.78). ESD teaching self-efficacy (M = 5.38, SD = 0.74), school support (M = 5.14, SD = 0.80), and pedagogical approach to SD (M = 5.12, SD = 0.75) were also at moderately high levels.

Table 2.
Descriptive Statistics for Key Study Variables Among Primary Science Teachers (N = 896)

Variable	M	SD
ESD Teaching Self-Efficacy	5.38	0.74
Attitude Towards SD	5.51	0.72
Knowledge About SD	5.49	0.78
School Support	5.14	0.80
Pedagogical Approach to SD	5.12	0.75

Structural Model

Figure 1 displays the tested structural model. Overall model fit was acceptable (χ^2/df = 1.997, CFI = 0.939, TLI = 0.937, RMSEA = 0.033). The structural model accounted for 25% of the variance in science teachers' pedagogical approach (R^2 = 0.25), indicating a moderate effect size according to Cohen's (1988) guidelines.

Predictor Strength

Table 3 shows the standardised regression weights (β). ESD teaching self-efficacy emerged as the strongest predictor of pedagogical approach (β = 0.387, p < .001), consistent with recent studies that highlight the critical role of teachers' confidence in implementing sustainability practices in the classroom (Daumiller et al., 2024; Tomas et al., 2017).

School support was also a significant, though weaker, predictor (β = 0.111, *p* = .014), echoing findings by Seiser et al. (2022) and Müller et al. (2020), who emphasised the importance of institutional leadership and structural support in enabling the enactment of Education for Sustainable Development (ESD).

Contrastingly, attitudes towards SD (β = 0.030, p > .05) and knowledge about SD (β = 0.050, p > .05) were not statistically significant predictors in the model. However, these results should not be

interpreted to mean that attitude and knowledge are unimportant. Rather, recent studies suggest these constructs may exert their influence indirectly through their impact on self-efficacy. This interpretation aligns with emerging literature indicating that self-efficacy mediates the relationship between belief-related variables and teaching or pro-environmental behaviour in ESD contexts (Rahmania, 2023; Zhang & Cao, 2025).

Table 3.
Standardised Regression Weights Predicting Pedagogical Approach

Path		β	p-value
Self-Efficacy	→ Pedagogical Approach	0.387	< .001
School Support	→ Pedagogical Approach	0.111	.014
Attitude	→ Pedagogical Approach	0.030	> .05
Knowledge	→ Pedagogical Approach	0.050	> .05

These results indicate that teachers' self-efficacy in teaching ESD and the support they receive from their schools are the key drivers of sustainable pedagogical practice. Although teachers reported high attitudes and knowledge levels, these factors did not directly translate into classroom implementation. Instead, they appear to exert influence indirectly by enhancing self-efficacy (see Figure 1). The findings underscore the importance of professional development initiatives that build self-efficacy and of institutional support that encourages and resources sustainability-oriented teaching.

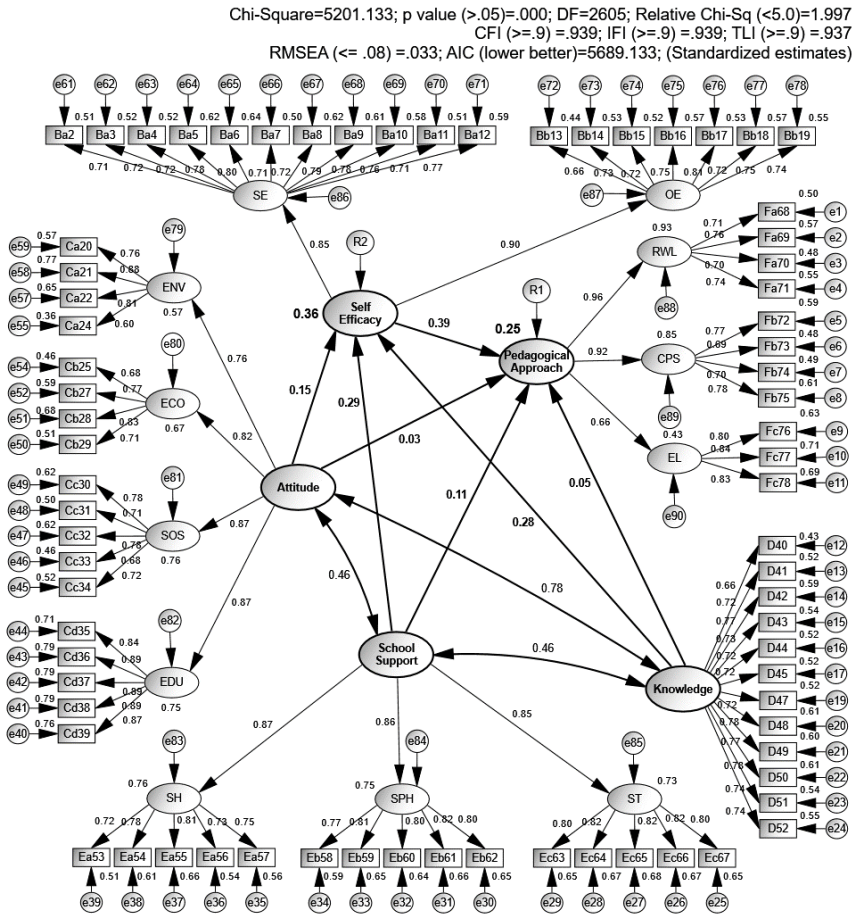

Figure 1. *Structural Model Illustrating the Predictive Factors of Science Teachers' Pedagogical Approaches to Sustainable Development*

DISCUSSION

This study sought to determine which among four key variables (ESD teaching self-efficacy, attitudes toward sustainable development, knowledge about sustainable development, and school support) most strongly influence science teachers' pedagogical approaches to sustainability. The results revealed that self-efficacy was the most robust predictor, followed by school support, while attitudes and knowledge did not show significant predictive power. These findings suggest a shift in emphasis from merely holding positive beliefs or factual understanding to the capacity and contextual support needed to enact them in classroom practice.

Although attitudes and knowledge received the highest mean scores (M = 5.51 and M = 5.49, respectively), they did not significantly predict pedagogical practices in this model. This may appear counterintuitive, yet it aligns with a growing body of research suggesting that while these factors are essential, they often operate indirectly. According to Ajzen's (1991) Theory of Planned Behaviour, favourable attitudes alone are insufficient without perceived control over behaviour. Our findings reflect this limitation, underscoring that attitudes and knowledge, though important, may not directly translate into action unless channelled through a strong sense of efficacy.

Recent research supports this interpretation. For instance, Acut et al. (2024) found that ESD knowledge contributes significantly to building teachers' confidence in integrating sustainability into their pedagogy, indicating that knowledge functions more as an enabler of self-efficacy than a direct driver of practice. Similarly, Ya'acob and Abdullah (2023) reported only a weak correlation (r = 0.455) between teachers' attitudes and their actual sustainable teaching practices, suggesting that knowledge may shape attitudes, but this does not necessarily lead to classroom enactment. These studies reinforce the notion that knowledge and attitude may be necessary but not sufficient conditions for pedagogical transformation. Taken together, these findings highlight the mediating role of self-efficacy in converting beliefs and awareness into practice. As such, professional development programs should not merely aim to inform or persuade but should prioritise strategies that actively cultivate teachers' confidence through reflective, experiential, and peer-supported learning environments.

Our finding that school support was a significant but secondary predictor ($\beta = .111$, $p = .014$) aligns with Self-Determination Theory (Deci & Ryan, 2000), emphasising the need for supportive social contexts. Leadership engagement, time allocation, and resource availability were found to be crucial enablers in other studies (Boeve-de Pauw et al., 2022; Yang et al., 2024). Without such scaffolding, teachers may struggle to translate ESD aspirations into sustained classroom practices, even when they possess strong self-efficacy.

Surprisingly**,** attitudes and knowledge, despite scoring highest in descriptive measures (M = 5.51 and M = 5.49, respectively), were not significant predictors. This reinforces Ajzen's (1991) Theory of Planned Behaviour, which asserts that attitudes alone are insufficient for behaviour change without accompanying perceptions of control. While it might be assumed that knowledge is a prerequisite for action, these findings reflect a growing recognition that knowledge is necessary but not sufficient. As Gómez-Gómez and García-Lázaro (2023) noted, high environmental concern among teachers does not lead to implementation unless supported by pedagogical confidence.

These findings warrant a rethinking of how professional development is structured. Programs focusing solely on content transmission or attitude shifts may have limited impact unless paired with experiential, reflective, and peer-based learning that builds ESD teaching self-efficacy. Maslamany et al. (2025) emphasised that knowledge and attitudes exert their effect on pedagogy indirectly by enhancing confidence, which, in turn, catalyses instructional change. In other words, self-efficacy may function as a psychological "gateway" variable, mediating the influence of beliefs on behaviour.

This interpretation aligns with Zhang and Cao's (2025) findings, which demonstrated that pro-environmental attitudes and norms significantly affected behaviour only when self-efficacy was high. Rahmania (2023) also highlighted how self-efficacy mediates the link between behavioural intentions

and sustainable teaching actions, underscoring the transformative potential of targeted confidence-building interventions.

From a policy and leadership perspective, these findings point to strategic implications. First, teacher education and professional development programs should move beyond informational delivery to include immersion in real-world sustainability teaching, coaching, and collaborative curriculum design. Second, school leadership should actively support ESD through structural enablers, such as time, autonomy, peer learning opportunities, and recognition. Finally, curriculum frameworks should explicitly integrate self-efficacy-enhancing pedagogical strategies, rather than assuming that knowledge acquisition alone will translate into practice.

Summarily, this study reinforces that fostering robust teaching self-efficacy and creating supportive institutional ecosystems are central to enabling science teachers to operationalise sustainability education. These findings can inform the design of teacher development programs that prioritise practical application and empowerment, guide school leaders in cultivating ESD-conducive environments, and support curriculum developers in aligning national ESD aspirations with classroom realities.

CONCLUSION

This study examined how ESD teaching self-efficacy, attitudes toward sustainable development, knowledge of sustainable development, and school support serve as predictors of science teachers' pedagogical approaches to sustainable development. Using structural equation modelling, the results revealed that ESD teaching self-efficacy was the strongest and most significant predictor, followed by school support. In contrast, attitudes and knowledge about sustainable development did not significantly contribute to predicting teachers' sustainable pedagogical practices. These findings suggest that belief in one's teaching capability and the presence of a supportive institutional environment are more influential than personal attitudes or knowledge alone.

The implications of these findings are important for teacher education and school leadership. Professional development programmes should go beyond content delivery and focus on strengthening teachers' confidence to implement ESD through active, experiential, and reflective learning opportunities. At the same time, school administrators must foster a culture that supports sustainability education by providing time, resources, and encouragement for interdisciplinary and innovative teaching. Building both teacher self-efficacy and systemic support can enhance the integration of sustainability in science classrooms and contribute meaningfully to national and global education for sustainable development goals.

This study is subject to several limitations. First, the use of self-reported data may have introduced social desirability bias, as participants could have overestimated their capabilities or support systems. Second, the cross-sectional design limits the ability to draw causal inferences between the predictors and pedagogical practices. Third, the sample consisted solely of Malaysian primary science teachers, which may constrain the generalizability of the findings to other subjects, educational levels, or national contexts.

In light of these limitations, future research should consider mixed-method or longitudinal designs to better capture the dynamic nature of teacher beliefs, contextual influences, and pedagogical change. Studies could also explore the mediating or moderating roles of self-efficacy in greater depth, particularly concerning how knowledge and attitudes are translated into action. Moreover, comparative studies across different school types, regions or countries could reveal systemic or cultural variations in ESD implementation. Finally, incorporating classroom observations or student feedback could provide a more holistic and objective understanding of actual teaching practices related to sustainable development.

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