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Research article

Self-efficacy, attitudes, knowledge, and school support as predictors of STEM teachers' pedagogical approach to sustainable development

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Abstract: This study aims to assess the influence of STEM teachers' ESD teaching self-efficacy, attitudes towards Sustainable Development (SD), knowledge about SD, and school support on their adoption of SD-oriented pedagogical approaches in alignment with the Sustainable Development Goals (SDGs). A quantitative research design was employed, involving surveys administered to 896 primary school STEM teachers across Malaysia, selected through stratified random sampling. The data were analyzed using AMOS Version 26 software via Structural Equation Modeling (SEM). Findings indicate that while teachers' attitudes towards SD reported the highest mean score ($M = 5.51$, $SD = 0.719$), followed closely by their knowledge of SD ($M = 5.49$, $SD = 0.784$), these factors did not directly influence their pedagogical approaches to SD. However, the study revealed significant direct effects of attitudes towards SD ($\beta = .251$, $p < .001$), knowledge about SD ($\beta = .223$, $p < .001$), and school support ($\beta = .272$, $p < .001$) on ESD teaching self-efficacy. Furthermore, ESD teaching self-efficacy exhibited a significant and positive direct effect on pedagogical approaches ($\beta = .387$, $p < .001$), underscoring the critical role of teacher confidence in implementing SD-focused STEM education. Additionally, school support also demonstrated a positive direct effect on pedagogical approaches ($\beta = .111$, $p = .014$), highlighting the importance of institutional backing in promoting effective SD pedagogy. The results suggest that enhancing teachers' self-efficacy through positive attitudes, robust knowledge, and strong school support are key strategies for fostering effective SD-oriented STEM education in line with the SDGs.

Keywords: STEM teachers, education for sustainable development (ESD), self-efficacy, attitude, pedagogical approach

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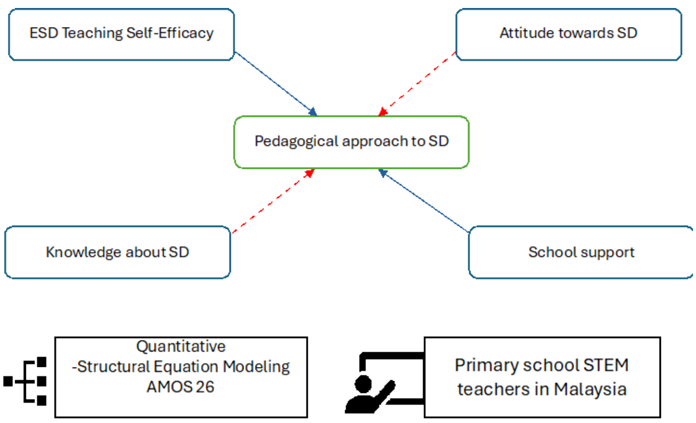
ESD integration with STEM education is difficult. Teachers struggle with ESD's multidisciplinary character, prefer teacher-centered techniques over student-centered, inquiry-based learning, and lack the skills to deliver it effectively. Inconsistencies in resources, training, and school support limit STEM ESD implementation.



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1 Introduction

Sustainable development has become a pressing concern in the 21st century and hence sustainability principles need to be incorporated into STEM education, which is important for developing environmentally literate citizens. Science is a fundamental aspect of STEM and hence has a crucial function in facilitating its integration, enabling its deliberate introduction at early stages at the elementary levels of our educational system. Science helps us to describe and explain the natural world; cultivate curiosity and encourage critical reasoning. Science encourages observation and experimentation, helping us develop an understanding of scientific ideas; thinking that is both critical and creative. Being STEM educators themselves, science teachers are crucial to the advancement of a student as they navigate through these processes and seek unity between scientific concept and application in reality. Integrating ESD as cross-curricular element enforces STEM education in terms of promoting long-term scientific and technological consequences on environment, economy and society.

Despite the clear importance of ESD in achieving the Sustainable Development Goals (SDGs), its implementation in STEM education encounters significant barriers. These include inadequate teacher training, limited resources, and inconsistent support from educational institutions, which collectively hinder the effectiveness of ESD initiatives (Sass et al., 2020; Anderson et al., 2020). Moreover, cultural and institutional biases towards conventional teaching methods further complicate the adoption of ESD practices (Said and Ahmad, 2021). Such challenges underscore the need for a supportive school environment and well-prepared educators who are confident in their ability to integrate ESD into their teaching practices.

This paper explores how factors such as STEM teachers' ESD teaching self-efficacy, their attitudes towards SD, knowledge about SD and the support they receive from their schools influence their ability to implement SD-oriented pedagogies. Understanding these dynamics is crucial for developing effective strategies that enhance the promotion of sustainable development through STEM education, thus contributing directly to the global SDGs. The analysis presented herein draws on contemporary theories and empirical research to propose actionable recommendations for educators and policymakers aimed at fostering a robust educational ecosystem where sustainable development is seamlessly integrated into STEM education.

2 Theoretical framework

The present research is based on four theoretical frameworks: The Social Cognitive Theory (SCT), the Theory of Planned Behavior (TPB), Expectancy-Value Theory (EVT) and Self-Determination Theory (SDT). These frameworks explains broadly to comprehend the factors, that influence the STEM teachers in adopting sustainability-based teaching approaches in STEM education.

The Social Cognitive Theory (SCT), introduced by Bandura (1986), emphasizes the role of self-efficacy, which is individuals' beliefs in their abilities, along with the external factors that can either facilitate or hinder their actions. In the context of this study, SCT suggests that the combination of teachers' confidence in their capacity to teach for sustainable development and institutional support significantly influences their classroom practices. Teachers who are confident in their ability to effectively teach sustainability and who receive institutional support are more likely to adopt and sustain sustainable teaching methods in their STEM classrooms.

The Theory of Planned Behavior (TPB), formulated by Ajzen (1991), asserts that an individual's actions are driven by intentions, which are influenced by attitudes, subjective norms, and perceived behavioral control. In this study, TPB suggests that STEM teachers' adoption of sustainable teaching methods is shaped by their attitudes toward sustainability, confidence in teaching for sustainable development, and perceived support from their school environment (Manasia et al., 2019; Puertas-Aguilar et al., 2021). Teachers who view sustainability positively and feel confident and supported in teaching these concepts are more likely to integrate ESD into their pedagogical approaches.

Expectancy-Value Theory (EVT) focuses on how the value teachers assign to teaching sustainability and their expectations for successful outcomes influence their pedagogical choices. It argues that a deeper knowledge about sustainability leads teachers to value these pedagogical approaches more highly, which boosts their motivation and commitment to these methods.

Self-Determination Theory (SDT) emphasizes the importance of meeting teachers' needs for autonomy, competence, and relatedness to enhance motivation and self-efficacy. In the context of this study, strong institutional support is posited to fulfill these needs, thereby encouraging teachers to engage more deeply with sustainable education practices.

Together, these theories form a cohesive framework that elucidates the complex interplay between self-efficacy, attitudes toward SD, knowledge about SD and school support in shaping teachers' pedagogical approaches for sustainable development. This framework is instrumental in examining how these factors collectively influence teachers' decisions to adopt sustainability-focused teaching practices, all of which are crucial for the successful integration of sustainability in STEM education.

3 Literature review

In educational psychology, self-efficacy is acknowledged as essential for effective teaching, particularly within the complex interdisciplinary context of STEM education. Bandura's foundational work (1997) established that higher self-efficacy among teachers correlates with enhanced pedagogical practices. However, Yahiaoui (2024) challenges this assumption, showing that pedagogical training does not necessarily enhance self-efficacy or shift teaching approaches towards more student-centered methods, indicating a gap between traditional training modalities and the dynamic requirements of modern STEM education

(Yahiaoui, 2024). This suggests the need for innovative training approaches that are directly aligned with enhancing self-efficacy in practical teaching scenarios.

Further supporting the significance of self-efficacy, studies by Meiyanti et al. (2022) and Na & Isa (2024) illustrate that high self-efficacy not only boosts teaching effectiveness but also encourages the adoption of innovative teaching practices (Meiyanti et al., 2022; Na & Isa, 2024). Paisun et al. (2024) complement this viewpoint by linking effective classroom management to teachers' confidence in their abilities, thereby reinforcing the pivotal role of self-efficacy in educational outcomes (Paisun et al., 2024).

Attitudes towards sustainable development also critically influence STEM teachers' pedagogical decisions. Research highlights a strong link between positive attitudes and the likelihood of adopting educational methods that enhance problem-solving and interdisciplinary learning (Karpudewan & Khan, 2017; Barth et al., 2019). For instance, Voler & Flogie (2024) and Ramya (2023) observe that despite challenges, STEM teachers generally hold positive attitudes towards innovative methods like problem-based learning, which significantly facilitates the integration of these methods into STEM curricula, enhancing both critical thinking and problem-solving skills (Voler & Flogie, 2024; Ramya, 2023).

Moreover, the depth of teachers' knowledge in sustainable development is fundamental for employing innovative pedagogical approaches. A profound understanding of sustainability allows teachers to create interdisciplinary learning opportunities that bridge STEM education with real-world challenges such as climate change and social inequities, thus enriching the educational experience and making STEM education relevant to current global issues (Mogensen & Schnack, 2010; Albareda-Tiana et al., 2019; Baena-Morales et al., 2021; Vukelić, 2022).

However, the successful integration of Education for Sustainable Development (ESD) in STEM education heavily depends on institutional support. Effective school leadership and resource availability are crucial for creating an environment that fosters ESD. While schools that actively support ESD enable teachers to adopt innovative and sustainable teaching methods, many educators still face significant challenges due to insufficient training and resources (Borg et al., 2012; Aleixo et al., 2018; Mishra, 2017; Vukelić & Rončević, 2021).

Despite existing insights into how self-efficacy, attitudes, knowledge and school support influence ESD implementation, most studies examine these factors in isolation and focus primarily on secondary or tertiary education settings (Hofman et al., 2018; Van Poeck et al., 2019). There remains a distinct gap in research concerning how these factors interact collectively to shape pedagogical approaches in STEM education, particularly at the elementary level. This oversight highlights a critical need for comprehensive models that explore these interactions in primary education settings, which could provide deeper insights into the foundational stages of STEM education and its alignment with sustainable development goals.

3.1 The present study

The primary goal of the present study is to examine the factors that affect the adoption of sustainable pedagogical approaches in STEM classrooms, with a focus on the predictive roles of STEM teachers' ESD teaching self-efficacy, attitudes toward SD, knowledge about SD, and school support based on previous research findings (see Fig. 1). Three research questions guided the study:

1. What is the level of STEM teachers' ESD teaching self-efficacy, attitudes towards sustainable development, knowledge about sustainable development, school support in ESD implementation and pedagogical approach to sustainable development?
2. Do STEM teachers' ESD teaching self-efficacy, attitudes towards environmental sustainability, knowledge about sustainable development, and school support in ESD implementation have a direct effect on their pedagogical approach to sustainable development?
3. Do STEM teachers' attitudes towards sustainable development, knowledge about sustainable development and school support in ESD implementation have a direct effect on their ESD teaching self-efficacy?

Based on the research questions, the research hypotheses for this study were formulated as below.

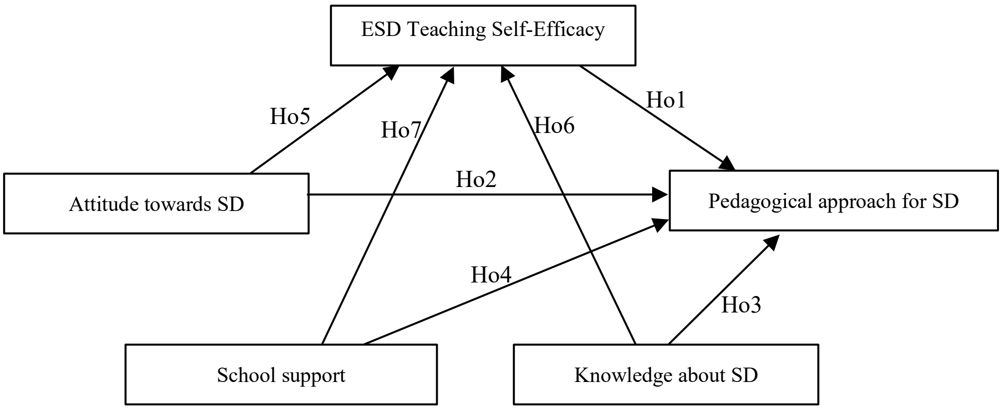
Research question 2

Ho1: ESD teaching self-efficacy has a significant direct effect on the pedagogical approach to SD.
Ho2: Attitude towards SD has a significant direct effect on the pedagogical approach to SD.
Ho3: Knowledge about SD has a significant direct effect on the pedagogical approach to SD.
Ho4: School support in ESD implementation has a significant direct effect on the pedagogical approach to SD.

Research question 3

Ho5: Attitude towards SD has a significant direct effect on ESD teaching self-efficacy.
Ho6: Knowledge about SD has a significant direct effect on ESD teaching self-efficacy.
Ho7: School support for ESD implementation has a significant direct effect on ESD teaching self-efficacy.

Figure 1. The hypothesised model of the study



4 Method

The study utilised a non-experimental research strategy, notably employing a quantitative approach to investigate the correlations among many essential variables. This approach allowed the researcher to examine the associations between STEM teachers' self-efficacy in teaching Education for Sustainable Development (ESD), their attitudes toward Sustainable Development (SD), their knowledge about SD, the support they receive from their schools in implementing ESD, and their pedagogical approaches to SD. The researchers chose a causal correlational research method to evaluate the degree of causal correlations between these variables (Rottman & Hastie, 2014). This method was suitable for assessing the impact of predictor variables, such as self-efficacy, attitudes, knowledge, and school support, on the outcome variable, namely the teachers' pedagogical approach to sustainable development.

The data was analysed using structural equation modelling (SEM) using AMOS version 26 software to examine the direct effects between the independent and dependent variables. The study utilised the causal correlational design, which is a type of non-experimental methodology that does not require direct control or manipulation of the variables (Curtis et al., 2016). This methodology allowed the researcher to evaluate the influence of the identified elements on the teaching approaches of STEM teachers concerning sustainable development in a real-life context, without any experimental interference (Vasilyeva et al., 2018).

4.1 Data collection

The study specifically examined STEM teachers who teach science at primary schools in Malaysia. A stratified random selection technique was utilised to guarantee a representative sample of schools and teachers from diverse places throughout Malaysia. The sample size was determined using the methodology outlined by Hair et al. (2018). Therefore, the researcher chose a subset from the entire population of 38,173 primary science teachers in Malaysia, using the stratified random selection method in order to adhere to the sample size guidelines provided by Schumacker and Lomax (2010). According to these standards, it is advised to have a sample size of around 772 teachers. In order to compensate for any non-responses and missing data, an extra 30% (equivalent to 232 respondents) was included, resulting in a desired sample size of 1,004 teachers.

The process of gathering data involved the use of an online survey that was disseminated to the chosen schools via email. The survey was active for a duration of two months. The online tool used for the survey, Google Form, was set up to automatically stop accepting responses after the desired number of 1,004 responses was reached. Following the gathering of data, a thorough data cleansing procedure was conducted to remove any abnormal values, resulting in a final dataset consisting of 896 valid responses. The resulting sample size surpasses the minimum need, ensuring considerable statistical power for further studies, such as Structural Equation Modelling (SEM) and bootstrap testing.

4.2 Instrument

The survey used the subsequently validated tools for examining the key constructs. The study utilised a questionnaire adapted from the Education for Sustainable Development Knowledge and Beliefs (ESDK&B) (Stant, 2016) to assess STEM teachers' ESD self-efficacy to teach Education for Sustainable Development (ESD). Similarly, the survey used to assess teachers' attitudes towards ESD adapted from the study conducted by Biasutti and Frate (2017). The questionnaire used to evaluate knowledge on sustainable development (SD) adapted from the research conducted by Aye, Win, and Maw (2019). Similarly, the questionnaire used in this study to assess school support in ESD implementation was adapted from the research conducted by Amabile, Conti, Coon, Lazenby, and Herron (1996). The pedagogical approach to Sustainable Development (SD) was evaluated using an instrument adapted from Said & Ahmad (2021).

Three specialists in the fields of ESD, science education, teacher training, professional development, and data handling verified the accuracy and reliability of the questionnaire items through consultation. Three experts reviewed the instruments independently and made recommendations for minor revisions. Considering those ideas, amendments were implemented to the instrument before commencing the validation and pilot study, to enhance the comprehensibility for the participating teacher respondents and to improve the validity. The improvements consist of enhancing the clarity of items, using appropriate language, ensuring the relevancy of items, structuring sentences effectively, correcting spelling errors, and using acronyms correctly, all based on professional guidance. In addition, a number of elements were eliminated following expert advice since they were redundant and did not correspond with the dimensions or local context.

The survey for this study is divided into six main sections: Section A, B, C, D, E, and F. Section A contains demographic information about the participants, such as their gender, age, years of experience in scientific instruction, and qualifications. Sections B, C, D, E, and F consist of the main elements that participants are required to address by responding to the statements that represent each of the variables in this study. This instrument utilises a 7-point Likert scale. The 7-point Likert scale was chosen due to its capacity to elicit more intricate and accurate responses when compared to a 5-point scale. The reliability and validity of these modified instruments were evaluated and confirmed through a pilot study conducted with a sample of 100 STEM teachers. Table 1 presents the Cronbach's alpha coefficient for each construct evaluated in this study.

Table 1. The constructs, dimensions and reliability of questionnaire

Constructs	Dimensions	Items	Cronbach's Alpha
ESD Teaching Self-Efficacy	a. Personal Teaching Efficacy b. Teaching Outcome Expectancy	19	0.81
Attitude towards SD	a. Environment b. Economy c. Society d. Education	20	0.81
Knowledge about SD		13	0.90
School Support	a. School head support b. Science panel head support c. Colleague support	15	0.96
Pedagogical Approach for SD	a. Real-world learning b. Critical Problem Solving c. Experiential Learning	11	0.94

4.3 Data analysis method

To address the research objectives, Structural Equation Modeling (SEM) was employed as the primary data analysis technique using AMOS 26 software. The use of SEM is appropriate for this study since it enables the evaluation of complex relationships between numerous independent and dependent variables simultaneously. This makes it a suitable technique for evaluating direct effects.

The analysis was conducted in two primary phases. The validity and reliability of the constructs related to ESD teaching self-efficacy, attitudes towards environmental sustainability, attitudes towards sustainable development, knowledge about sustainable development, school support in ESD implementation, and pedagogical approaches to sustainable development were assessed using confirmatory factor analysis (CFA) in the measurement model evaluation. Confirming the accuracy of the measurement tools was a crucial step before moving on to the structural model.

Subsequently, the structural model was evaluated to examine the hypothesised direct effects. The study specifically investigated the direct effect of STEM teachers' ESD teaching self-efficacy, attitudes towards sustainable development, knowledge about sustainable development and school support in ESD implementation on their pedagogical approach to sustainable development. In addition, the model examined the direct effect of STEM teachers' attitudes towards sustainable development, their knowledge about sustainable development, and the level of support they receive from their schools on their self-efficacy in teaching Education for Sustainable Development (ESD).

The adequacy of the model fit was assessed using fit indices including the Chi-square (χ^2), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA). The stability and significance of the direct impacts were evaluated using bootstrap techniques. This comprehensive methodology guaranteed that the causal connections between the variables were precisely evaluated, yielding strong insights into the elements that affect STEM teachers' teaching methods in sustainable development within STEM education.

5 Results

To answer the first research question, descriptive statistical measures by using mean and standard deviation were used to analyse the levels of STEM teachers' SD teaching self-efficacy, attitudes towards SD, knowledge about SD, school support in SD and their pedagogical approach to SD. The outputs from the descriptive statistical analysis are presented in the Table 2.

Table 2. Mean and standard deviation of variables under study

Variables	**Mean**	**SD**
ESD Teaching Self-efficacy	4.82	0.74
Attitude Towards SD	5.51	0.72
Knowledge about SD	5.49	0.78
School Support in ESD	4.91	0.84
Pedagogical Approach to SD	4.71	0.84

**Level:1.00-3.99(Low), 4.00-5.99(Moderate), 6.00-7.00(high) SD: Standard Deviation*

The analysis of STEM teachers' competence in Sustainable Development (SD) reveals that teachers exhibit moderate levels in all measured variables. The highest scores were observed for attitudes towards sustainable development (M = 5.51, SD = 0.719), closely followed by knowledge of sustainable development (M = 5.49, SD = 0.784). The level of school support in sustainable development was moderately lower (M = 4.91, SD = 0.838), followed by ESD teaching self-efficacy (M = 4.82, SD = 0.736) and the pedagogical approach to sustainable development (M = 4.71, SD = 0.836). The findings indicate that although STEM teachers possess a considerable level of attitudes and knowledge regarding sustainable development, there is still potential for enhancement in aspects such as self-efficacy and teaching methods.

This study tested measurements' reliability and validity using comprehensive statistical testing. The reliability assessment used Cronbach's Alpha coefficients for Construct Reliability (CR) and Average Variation Extracted. These coefficients determined how much variety each construct represented. All variables had Cronbach's Alpha coefficients over 0.80, indicating good internal consistency. The assessments' variable, convergent, and discriminant validity were assessed. Fornell and Larcker's formula was used to calculate composite reliability (CR) and average variance extracted (AVE) using confirmatory factor analysis (CFA). The analysis showed all variables satisfied the requirements. The results demonstrate the constructs' reliability and validity, verifying the research's integrity.

Table 3. Examination of construct convergent validity

Variable	**Dimension**	**Factor Loading**	**Average Varian Extract**	**Construct Reliability**
		FL	**AVE (>0.5)**	**CR (>0.8)**
Attitude	ENV	.758	.691	.899
	ECO	.820		
	SOS	.874		
	EDU	.868		
Knowledge	D40	.659	.546	.935
	D41	.722		
	D42	.769		
	D43	.733		
	D44	.722		
	D45	.720		
	D47	.723		
	D48	.779		
	D49	.775		
	D50	.780		
	D51	.738		
	D52	.742		
Pedagogical Approach	RWL	.965	.738	.892
	CPS	.924		
	EL	.656		
School Support	SH	.871	.745	.898
	ST	.855		
	SPH	.864		
Self-Efficacy	SE	.846	.761	.864
	OE	.898		

All measured variables have factor loading values above 0.5. The AVE of Attitude achieved (.691), Knowledge (.546), Pedagogical Approach (.738), School Support (.745) and Self-Efficacy (.761). The reliability of the construct Attitude achieved (.899), Knowledge (.935), Pedagogical Approach (.892), School Support (.898) and Self-Efficacy (.864). Based on this final match, it proves that the final measurement model that has combined items has good convergent validity to build a structural model.

The overall accuracy of the measurement model was confirmed through Confirmatory Factor Analysis, as shown in Table 4. The model's adequacy is reflected by various fit indices. The model's p-value (PROB) is less than .05, standing at .000, which signifies statistical significance. The Root Mean Square Error of Approximation (RMSEA) is well below the .08 threshold at .033, indicating a good fit. The Incremental Fit Index (IFI) and the Comparative Fit Index (CFI) are both above the accepted level of .90, with values of .939, suggesting the model is a good fit for the observed data. The Tucker-Lewis Index (TLI) also exceeds the .90 benchmark at .937, further supporting the model's fit. Lastly, the ratio of the chi-square to degrees of freedom (Chisq/df) is under the recommended maximum of 5, with a value of 1.997, which falls into the acceptable range, demonstrating a satisfactory level of parsimony in the model. Overall, these indicators collectively confirm the soundness of the measurement model used in the study.

Table 4. Overall measurement model matching accuracy

Indicator	**Value Indicator Accepted**	**Confirmatory Factor Analysis**
Absolute Fit Indices		
PROB (P-Val)	>. 05	.000
RMSEA	<. 08	.033
IFI	>. 90	.939
Incremental Fit Indices		
CFI	>. 90	.939
TLI	>. 90	.937
Parsimony Fit Indices		
Chisq/df	<. 50	1.997

5.1 Structural model

Modifications were made to the measurement model to develop the structural model. The path diagram representing the final structural model and the direct effects of ESD teaching self-efficacy, attitudes towards SD, knowledge about SD, school support, and pedagogical approaches for SD is presented in Figure 2. Figure 3 depicts the structural model that emerged after modifications. Upon examining the model fit, it was determined that all indices, such as chi-square (1.997), RMSEA (.033), CFI (.939), IFI (.939), and TLI (.937), met the required benchmarks, with all factor loadings surpassing the .60 threshold. Consequently, this structural model is suitable for proceeding with the analysis of hypotheses to address the research questions.

Figure 2. Standardised estimates from the SEM (path diagram)

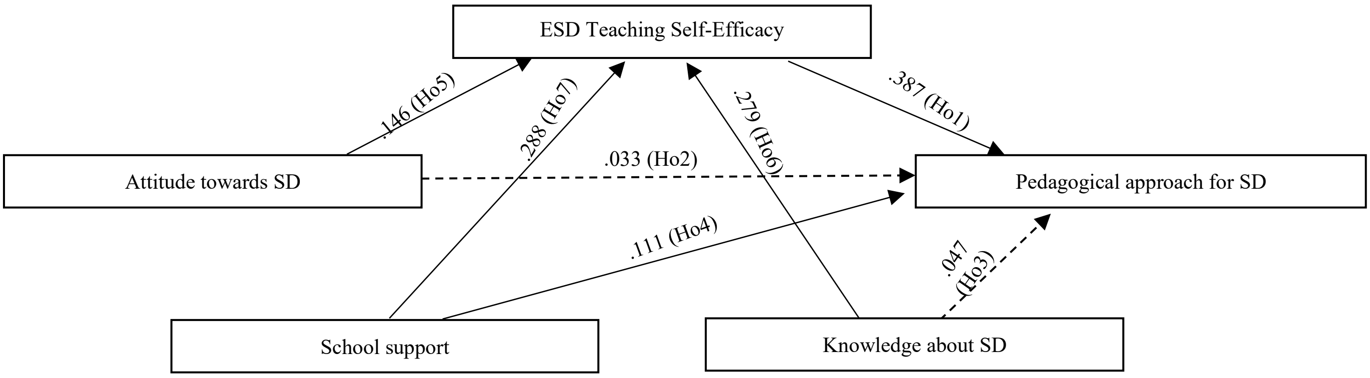
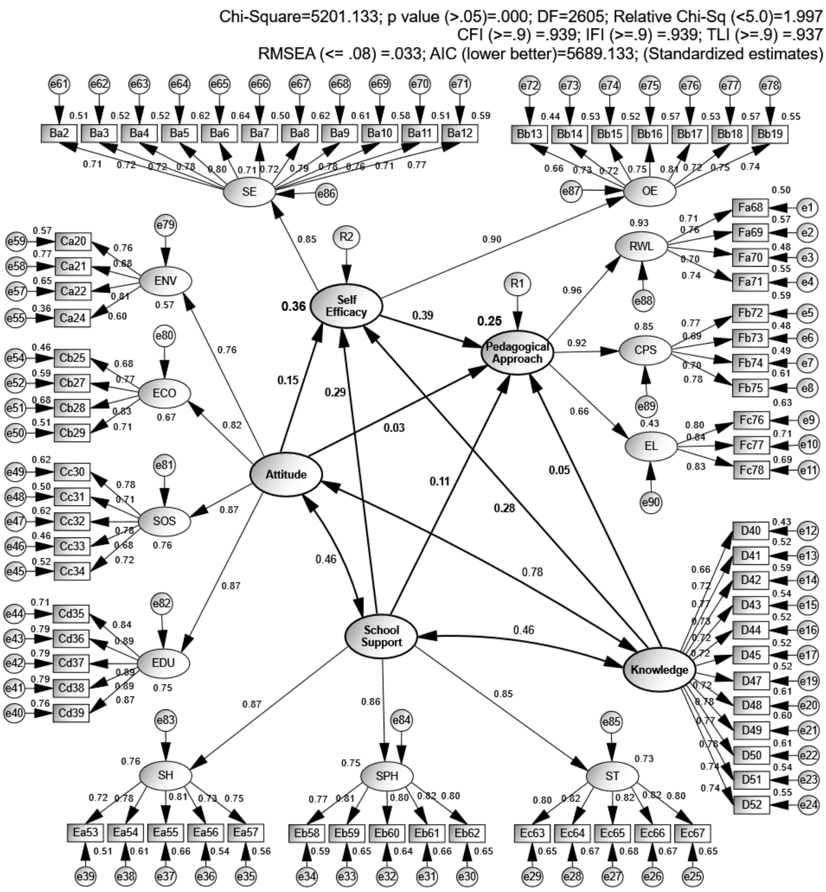


Figure 3. Structural model



The second research objective of this study aims to investigate the direct effects of ESD teaching self-efficacy (SE), attitudes towards SD (AT), knowledge about SD (KN), and school support (SS) on teachers' pedagogical approaches for SD (PA). Additionally, the third research purpose aims to investigate the direct effects of attitudes towards sustainable development (AT), knowledge about sustainable development (KN), and school support (SS) on ESD teaching self-efficacy (SE). To examine these relationships, the study developed a framework consisting of seven hypotheses. These hypotheses present the anticipated paths through which the variables may exert effect. The evidence supporting these paths, represented as regression coefficients, is systematically shown in Table 5. This table summarises the fundamental relationships within our model.

Table 5. Path coefficients and probability values of the variables of the model

Ho	Path			Beta	Estimate	S.E.	C.R.	Significant	Result
Ho1	SE	→	PA	.387	.571	.077	7.409	.000	Supported
Ho2	AT	→	PA	.033	.053	.103	.511	.609	Not supported
Ho3	KN	→	PA	.047	.061	.082	.741	.458	Not supported
Ho4	SS	→	PA	.111	.169	.069	2.448	.014	Supported
Ho5	AT	→	SE	.146	.158	.068	2.324	.020	Supported
Ho6	KN	→	SE	.279	.246	.054	4.535	.000	Supported
Ho7	SS	→	SE	.288	.296	.049	6.021	.000	Supported

Note: Significant at level $p<0.05$

The path analysis confirmed the first hypothesis (Ho1), indicating that teachers' self-efficacy in teaching sustainable development (SD) had a significant and positive direct effect on their pedagogical approach to SD ($\beta = .387$, $p < .001$). The data analysis provided evidence that teachers' self-efficacy significantly and directly influences their pedagogical approaches to sustainability development. Despite initial predictions, Ho2 was not supported. The attitudes of STEM teachers towards SD did not have a significantly direct impact on their pedagogical approach to SD ($\beta = .033$, $p = .609$). This suggests that only having a positive attitude towards SD is not enough to have a major impact on educational practices. Similarly, the hypothesis Ho3 was not supported. The level of knowledge about sustainable development (SD) did not have a statistically significant effect on teachers' pedagogical approach to SD ($\beta = .033$, $p = .609$). This suggests that possessing knowledge of SD alone is not enough to have an enormous effect on methods of instruction. On the other hand, Ho4 was supported.

The study found that school support has a notable and favourable impact on pedagogical approaches toward sustainable development ($\beta = .111$, $p = .014$). This highlights the crucial role of institutional support in promoting sustainable development pedagogy. The study provided support for Ho5, indicating that teachers' attitude towards SD has a significant impact on their self-efficacy ($\beta = .146$, $p = .020$). This suggests that having a positive attitude towards SD increases teachers' confidence in their ability to teach SD. H06 was supported by the analysis. Understanding of SD has a notable and favourable impact on self-efficacy ($\beta = .279$, $p < .001$), indicating that knowledge of SD enhances a teacher's belief in their abilities.

The path analysis also verified the hypothesis H07. The study found that school support has a strong and positive impact on ESD teaching self-efficacy ($\beta = .288$, $p < .001$). This suggests that when teachers receive support from their school, it enhances their confidence in their abilities to teach SD. Upon reviewing the complete set of path analysis findings, it is clear that attitudes towards sustainable development (SD) and knowledge of SD do not have a direct effect on the pedagogical approach to SD. However, they do have a considerable impact on ESD teaching self-efficacy, which in turn may influence STEM teachers' pedagogical approach to SD. Nevertheless, the support provided by schools has a direct impact on both the improvement of teachers' belief in their abilities to teach effectively and the instructional methods used to promote sustainable development.

6 Discussion

This study marks a pivotal contribution to understanding the dynamics shaping STEM teachers' implementation of Education for Sustainable Development (ESD). It emphasizes that while self-efficacy in ESD teaching and school support substantially drive effective pedagogical approaches, attitudes and knowledge about sustainable development surprisingly do not directly influence these educational strategies. This aligns with findings from Boeve-de Pauw et al. (2022) and Murphy et al. (2021), who highlight self-efficacy as a key factor in adopting interdisciplinary and inquiry-based methods, crucial for incorporating sustainability into STEM education.

The results reveal that self-efficacy is not only pivotal on its own but is also significantly enhanced through structured professional development and strong institutional support (Fathurohman & Amri, 2023; Murphy et al., 2021). These insights emphasize the necessity of school systems facilitating robust support mechanisms, such as access to resources, leadership, and professional learning communities, which are integral to the successful implementation of sustainability education. Contrary to earlier assumptions, findings from Nousheen et al. (2020) and Malandrakis & Papadopoulou (2019) suggest that positive attitudes and extensive knowledge of sustainability, while contributing to a teacher's motivation, are insufficient to catalyze pedagogical changes without the backing of substantial self-efficacy and institutional support.

Additionally, the study sheds light on the critical role of external factors, particularly school support, which not only enhances resource availability but also bolsters teachers' confidence in applying ESD principles effectively. This dual support system proves essential as teachers navigate the complexities of integrating sustainability into their teaching practices, challenging previous views that emphasized individual teacher efforts over systemic support (Handtke et al., 2022; Glassmeyer et al., 2019).

The insights from this research suggest a shift in focus for future ESD interventions from merely enhancing knowledge and attitudes to strengthening practical support and professional development opportunities. This approach aims to equip teachers with the necessary skills and confidence to implement sustainability education, thereby ensuring that ESD becomes an integral part of STEM curricula. These findings offer a foundation for developing targeted interventions that address both the perceived and actual barriers to ESD implementation, thus fostering an educational environment conducive to sustainable development.

7 Implications

The results of this study have significant implications for the field of STEM education, particularly within the framework of Education for Sustainable Development (ESD). By demonstrating the pivotal roles of teacher self-efficacy and school support in the effective implementation of ESD, this research suggests a systemic shift in how sustainability is integrated into STEM curricula. For policymakers, there is a clear indication that educational policies need to prioritize institutional support and professional development to enhance teacher self-efficacy. This entails embedding ESD thoroughly in both national and regional STEM curriculum standards to ensure that sustainability concepts are not only included but actively promoted within educational frameworks.

In educational practice, the findings advocate for the development of supportive school environments that facilitate sustainability-focused pedagogy. It becomes essential to provide teachers with adequate resources, opportunities for professional growth, and a collaborative professional community. Such an environment would not only bolster teachers' confidence in applying ESD principles but also enhance their competence to do so effectively. Additionally, teacher education programs, both pre-service and in-service, need to incorporate comprehensive ESD training to prepare educators to integrate sustainability in science, technology, engineering, and mathematics education.

For future research, this study opens avenues for exploring the dynamics between ESD teaching self-efficacy, attitudes towards sustainable development, knowledge about sustainable development, and school support in various educational contexts. Understanding how these factors interact can lead to more effective strategies for adopting ESD in STEM education. Longitudinal studies could provide deeper insights into how changes in teacher self-efficacy over time influence the implementation of sustainability practices in schools. Moreover, expanding the research focus beyond STEM to include other disciplines could enrich our understanding of how ESD can be effectively implemented across the educational spectrum.

Overall, this research emphasizes the need for a comprehensive approach to enhance ESD in STEM education. By focusing on strengthening teachers' self-efficacy, providing robust school support, and fostering positive attitudes and knowledge about sustainability, educational stakeholders can ensure that ESD becomes an integral and effective part of STEM education. This not only advances STEM education but also contributes significantly to the global goals of sustainable development.

8 Limitations

Although this study provides useful information on the dimensions which affect how ESD is integrated within STEM education, it is important that we realise the limitations of this study. The cross-sectional nature of the study limit concluding with certainty that ESD teaching self-efficacy, attitudes towards Sustainable Development (SD), knowledge about SD, school support and pedagogical approach to SD are mutually impacting one another. To determine causality and changes in these associations over time, longitudinal studies are needed.

Further, the study used self-reported teacher data that may have been prone to bias as participants could be more influenced to provide socially acceptable answers rather ones which truly reflected their attitudes, self-efficacy or instructional routines. This likely undermines the validity of the results, particularly regarding our understanding of how self-efficacy and attitudes impact instructional practices. This limitation could be addressed in future study by incorporating observational data or third-party evaluations of instructional approaches.

However, the study did not thoroughly examine the potential moderating or mediating effects of variables such as teachers' experience, school culture, or external environmental factors, which could significantly influence the correlations analyzed. These factors should be considered in future research to deepen our understanding of the conditions under which ESD can be effectively integrated into STEM education.

In summary, while this study advances our knowledge of the critical elements influencing the integration of ESD into STEM education, caution is advised in interpreting the results due to the study's methodological constraints and the possible influence of unexamined variables. Future studies should aim to develop a more robust and comprehensive understanding of how to better support teachers in implementing ESD across different educational contexts.

Research ethics

Author contributions

Kavitha Maslamany contributed to the conceptualization, methodology, data analysis, and writing of the original draft of the manuscript.

Chua Kah Heng provided significant guidance and support in enhancing the quality of the paper through critical revisions and suggestions.

Renuka Sathasivam assisted in refining the research framework and contributed to the final editing and review process.

Artificial intelligence

In the preparation of this article, Artificial Intelligence (AI) was utilized to assist with the writing process. Specifically, OpenAI's ChatGPT was employed to provide suggestions, improve language clarity, and ensure the consistency of the document. The AI software was also used to generate initial drafts and refine text segments according to specific academic standards. However, all content was thoroughly reviewed, edited, and validated by the author to ensure accuracy and originality. The AI was used solely as a tool to enhance the writing process and did not contribute to the research design, data analysis, or interpretation of findings.

Informed consent statement

Informed consent was obtained from all research participants. The in-service teachers who participated in the study provided their consent by agreeing to and completing the questionnaire, where the purpose and nature of the research were clearly explained before they began answering.

Data availability statement

The data supporting the results reported in this article were collected from in-service teachers through a questionnaire. Due to privacy and ethical restrictions, the data are not publicly available. However, de-identified data can be made available upon reasonable request to the corresponding author.

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Conflicts of interest

The authors declare no conflicts of interest. The funders had no role in the design of the study, data collection, analysis, interpretation of results, or in the decision to publish the findings.

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